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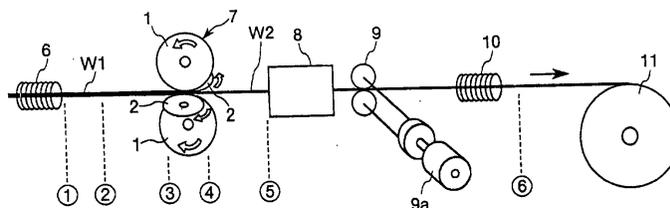
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(54) **HEAT−TREATED DEFORMED STEEL WIRE, AND METHOD AND APPARATUS FOR MANUFACTURING THE SAME**

(57) Arranged in tandem are a pre-heating unit 6, a four-side hot-rolling mill 7 and a quenching/cooling unit 8. A starting material W1 is rapidly heated to a hot-rolling temperature using the unit 6 and hot-rolled into a modified cross-section steel wire W2 assuming a pre-determined shape in cross section using the mill 7. The wire is then quenched under tension using the unit 8 immediately after its hot-rolling operation. The tension is

applied to the wire by a pinch roll 9 driven by a motor 9a, which is combined with a torque converter. Consequently, there is no variation in tension, and no variation in cross-sectional dimension in the wire. Disposed behind the unit 8 in tandem is an in-line post-heating coil 10 to realize a continuous tempering operation, so that the wire free from any small-radius bend and having been heat-treated, can be produced through a substantially single process.

FIG. 1



Description

TECHNICAL FIELD

[0001] The present invention relates to a modified cross-section steel wire and its production, wherein the steel wire, which has been subjected to a heat treatment, is for use in coil springs or the like and assumes, in cross section, a modified shape such as a square shape, a rectangular shape or a nearly trapezoidal shape.

BACKGROUND ART

[0002] Heretofore, it has been known to provide a coil spring, which is constructed of, for example, a modified cross-section steel wire and produced through a wire drawing process. In this drawing process, a starting material, i.e., a rolled steel bar assuming a circular shape in cross section is drawn to form such a modified cross-section steel wire, as shown in Fig. 5. Such drawn steel wire is then subjected to a quenching treatment which is followed by a tempering treatment such as an oil tempering treatment and the like. After that, as shown in a process shown in Fig. 5(a), the steel wire is coiled to form a coil spring, or further subjected to another process shown in Fig. 5 (b) after completion of such coiling process, in which another process the coil spring thus formed is subjected to a quenching and a tempering treatment using an electric furnace or the like.

DISCLOSURE OF THE INVENTION

[0003] However, since a conventional method for manufacturing a coil spring requires two process steps comprising a wire drawing step for drawing a modified cross-section wire or the like and a heat treatment step including a quenching and a tempering treatment, the conventional method suffers from the large number of its necessary process steps, which makes it difficult for the conventional method to reduce manufacturing costs.

[0004] Further, in the method for coiling the steel wire having been heat-treated as shown in Fig. 5(a), when the wire to be coiled has a wave, a twist and/or a slight bend in shape, the wire thus coiled is deformed in shape, thereby causing a decrease in yield of products. In this respect, however, even when the wire having been treated by the conventional method is subjected to a quenching and a tempering treatment through heating in the furnace, it is difficult to improve the products in quality. Due to this, a need still exists in the art for a steel wire-to-be-quenched which is improved in smoothness.

[0005] On the other hand, in order to obtain such a steel wire improved in smoothness, there is proposed a method for heating and quenching the steel wire under a proper tension. However, when the steel wire is heated to a high temperature, the thus heated steel wire is easily elongated in its longitudinal direction under tension

to reduce its cross-sectional area. In other words, when the tension applied to the steel wire varies, the cross-sectional area of the steel wire also varies. This is a problem inherent in the art.

[0006] Consequently, it is an object of the present invention to provide a method for producing a modified cross-section steel wire, wherein a starting material, i.e., a steel wire assuming a circular shape in cross section is continuously hot-rolled into a modified cross-section steel wire and simultaneously subjected to a quenching treatment through a heat treatment, whereby the modified cross-section steel wire having been heat-treated is produced through a single process step. In addition, it is another object of the present invention to provide a method for producing a modified cross-section steel wire having been heat-treated, wherein the steel wire is quenched under a stable tension free from any variations, which results in the steel wire excellent both in accuracy of dimensions and in smoothness of shape. Particularly, the present invention is useful for production of a coil spring constructed of a high-strength steel wire. Further, the present invention is also useful for production of various types of a modified cross-section steel wire serving as a square cross-section torsion bar and the like, which has a modified cross section and must be smooth in shape.

[0007] In order to accomplish the above objects of the present invention, a modified cross-section steel wire of the present invention and a method of its production are characterized in that: a starting material of the steel wire is rapidly heated to a hot-rolling temperature in a short period of time using an induction heating means and/or directly using a resistance heating means, hot-rolled into a modified cross-section steel wire having a predetermined cross section and then quenched immediately after completion of its hot-rolling operation.

[0008] In other words, when the starting material of the steel wire is rapidly heated in a short period of time by induction heating and the like, it is possible to avoid occurrence of a problem of decarbonization which often occurs in heating in an ordinary furnace and the like. It is also known that the induction heating or the like is effective in obtaining large quenching effects. When the steel wire is quenched immediately after completion of its hot-rolling operation, it is possible to avoid "grain growth" in the steel wire and also avoid Ar3 transformation in a surface layer portion of the steel wire. This permits the surface of the steel wire to be rapidly cooled to prevent the precipitation of ferrite, which makes it possible to quench the steel wire up to its surface layer portion. As is clear from the above description, by quenching the steel wire immediately after completion of its hot-rolling operation, it is possible to perform the hot-rolling and the quenching operation of the modified cross-section steel wire through a single process step. Further, the quenching operation makes it possible for the steel wire to be improved in strength relative to that subjected to a conventional quenching operation.

[0009] When the four-side hot-rolling mill is used to perform the above hot-rolling operation, it is possible to obtain the modified cross-section steel wire in an easy manner using a small number of mill stands.

[0010] Preferably, the modified cross-section steel wire is produced by: rapidly heating the starting material of the steel wire at a heating rate of equal to or more than 100 °C/s to a temperature of equal to or more than the Ac3 point in a short period of time; hot-rolling the thus heated starting material of the steel wire at a temperature of equal to or more than the Ar3 point into the modified cross-section steel wire having a predetermined cross section; and, quenching the thus hot-rolled modified cross-section steel wire at a temperature of equal to or more than the Ar1 point using the quenching/cooling means disposed adjacent to the hot-rolling mill in tandem therewith, immediately after completion of its hot-rolling operation. Preferably, this quenching/cooling means is disposed as close as possible to the hot-rolling mill. This makes it possible to perform the quenching operation of the steel wire immediately after completion of its hot-rolling operation, which prevents a so-called "grain growth" from occurring in the steel wire thus hot-rolled and therefore makes it possible to improve the thus immediately-quenched hot-rolled steel wire in hardness.

[0011] As described above, by hot-rolling the starting material of the steel wire into the modified cross-section steel wire using the hot-rolling mill, it is possible to obtain a spring steel wire which is free from any scratch and excellent in smoothness in its surface in contrast with a corresponding wire product produced through a conventional wire drawing process. Further, as for high alloy steels, though it is difficult to draw the high alloy steels since the high alloy steels are large in work hardening, the present invention makes it possible to draw the high alloy steels into a modified cross-section steel wire in an easy manner.

[0012] As for the above-mentioned quenching operation, in order to improve the hot-rolled steel wire in straightness, it is preferable to quench the modified cross-section steel wire under tension immediately after completion of the hot-rolling operation of the starting material of the steel wire. Further, in order to reduce variations in dimensions of the steel wire resulted from variations in tension applied to the steel wire, it is preferable to employ any one of a pinch roll, a wire take-up reel and a capstan unit which are driven by a drive unit combined with a torque converter capable of absorbing any variations in tension of the steel wire.

[0013] As described above, in performing a coiling operation of the steel wire to form a coil spring, a bend with a predetermined large radius of the steel wire does not affect the properties of the product. In contrast with this, when the steel wire to be coiled has a wave, a twist and/or a bend with a small radius in shape, the wire product thus coiled is deformed in shape, thereby causing a decrease in yield of the products. In the method of the

present invention, since the quenching operation of the steel wire is performed under tension applied to the steel wire immediately after completion of the hot-rolling operation, it is possible to obtain the spring steel wire which has been quenched and is excellent in straightness. This makes it possible to improve the thus quenched steel wire or product in yield when the product is coiled into a coil spring. Incidentally, in addition to the above use (coil spring), also in other uses for the steel wire such as a torsion bar and the like assuming a straight shape, it is possible to considerably reduce the number of necessary process steps such as a process step for straightening the steel wire and the like. This leads to a considerable reduction of the manufacturing cost.

[0014] However, since the steel wire having been heated to a high temperature for performing the quenching operation thereof is low in strength, there is a fear that the dimensions of the steel wire vary in cross section when the tension applied to the steel wire varies. Consequently, the present invention is characterized in that: using a pinch roll, a wire take-up reel and a capstan unit which are driven by a drive unit combined with a torque converter, any variations in tension in the steel wire is absorbed by such a torque converter, so that the tension of the steel wire is maintained at a predetermined level when the steel wire is quenched. This makes it possible for the present invention to obtain the steel wire which has been quenched, is free from variations in its cross section and excellent in dimension accuracy. Particularly, as for a modified cross section steel wire having a small diameter, such a small-diameter steel wire is large in variations in cross section when directly subjected to tension. However, this problem of variations in cross section of the steel wire can be solved in the present invention by using the torque converter through which a tension is applied to such a small-diameter steel wire when the steel wire is quenched. here, the term "drive unit combined with the torque converter" means not only a combination system constructed of the drive unit and the torque converter, but also any system for driving the steel wire through the torque converter.

[0015] In the present invention, it is preferable to continuously perform the quenching and the tempering operation of the steel wire by performing the quenching operation which is followed by an induction heating operation. In this induction heating process, the steel wire is heated to a tempering temperature thereof. After the steel wire reaches such a tempering temperature thereof, the steel wire is tempered. Preferably, such a tempering operation of the steel wire is continuously performed using the induction heating coil, wherein the induction heating coil is disposed in a downstream side of the quenching means or unit in a tandem manner.

[0016] In general, the method of the present invention is effective in producing the modified cross-section steel wire assuming, in cross section, either a square shape, a rectangular shape or a nearly trapezoidal shape. It is possible for the method of the present invention to pro-

duce the modified cross-section steel wire in an easy manner, wherein the steel wire has been quenched and has a tensile strength of equal to or more than 1600 N/mm².

[0017] An apparatus of the present invention for producing a modified cross-section steel wire having been heat-treated, comprises: an in-line pre-heating means or unit for heating a starting material of the modified cross-section steel wire to a hot-rolling temperature using an induction heating means or unit or directly using a resistance heating means or unit; a hot-rolling means or unit for hot-rolling the starting material into a modified cross-sectional steel wire having a predetermined cross section; a quenching means or unit for quenching the thus hot-rolled modified cross-section steel wire under tension applied thereto; and, a tension applying means or unit for applying a tension to the modified cross-section steel wire thus hot-rolled, wherein all the means or units are arranged in tandem.

[0018] Preferably, the hot-rolling means or unit is constructed of a four-side hot-rolling mill. Preferably, the tension applying means or unit is constructed of either a pinch roll, a wire take-up reel or a capstan unit driven by a drive unit provided with a torque converter for absorbing variations in tension appearing in the steel wire. Disposed in a downstream side of the quenching/cooling means or unit in tandem is an post-heating means or unit for heating the steel wire to a tempering temperature, which makes it possible for the apparatus of the present invention to continuously perform the quenching operation and the tempering operation of the steel wire.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

[Fig. 1] : a view illustrating in construction an embodiment of the apparatus of the present invention for producing the modified cross-section steel wire having been heat-treated;

[Fig. 2] : a view illustrating in configuration the cross section of an embodiment of the modified cross-section steel wire having been heat-treated, according to the present invention;

[Fig. 3]: a view illustrating rolls of the four-side hot-rolling mill in the embodiment of the present invention;

[Fig. 4]: a flow diagram illustrating the process steps of the embodiment of the present invention for producing the modified cross-section steel wire having been heat-treated;

[Fig. 5] : a flow diagram illustrating a method for producing a coil spring constructed of a conventional type modified cross-section steel wire having been heat-treated;

[Fig. 6] : a Table illustrating the chemical composition of the rolled steel wire of the embodiment of the

present invention;

[Fig. 7]: a Table illustrating the particulars of the modified cross-section steel wire having been heat-treated in the embodiment of the present invention;

[Fig. 8]: a Table illustrating temperatures measured in various positions of the apparatus in the embodiment of the present invention; and

[Fig. 9] : a Table illustrating one of examples of the mechanical properties of the modified cross-section steel wire having been heat-treated in the embodiment of the present invention.

[DESCRIPTION OF THE REFERENCE CHARACTERS]

[0020] 1:an upper and a lower horizontal roll; 2:a left and a right vertical roll; 6:an induction heating coil (i.e., an in-line pre-heating means or unit); 7:a four-side hot-rolling mill; 8:a water-cooled jacket (i.e., a quenching means or unit); 9: a pinch roll (i.e., a tensioning means); 9a:a motor combined with a torque converter; 10:an intertempering operation heating coil; 11:a wire take-up reel; W1:a starting material of a steel wire; and, W2:a modified cross-section steel wire.

BEST MODE FOR CARRYING OUT THE INVENTION

[0021] With reference to an embodiment of the present invention shown in the accompanying drawings, present invention will be described in a concrete manner. Fig. 1 is a view illustrating the concept of the present invention in construction with the use of an embodiment of an apparatus of the present invention for producing the modified cross-section steel wire having been heat-treated. Fig. 2 is a view illustrating in configuration the cross section of an embodiment of the modified cross-section steel wire having been heat-treated, wherein the steel wire is used in the embodiment of such an apparatus of the present invention. Fig. 3 is a view illustrating, in configuration, each of rolls of the four-side hot-rolling mill (i.e., a hot-rolling means or unit) used in the hot-rolling operation of the steel wire according to the present invention. Fig. 4 is a flow diagram illustrating the process steps required in producing the modified cross-section steel wire having been heat-treated according to the embodiment of the present invention.

[0022] In Fig. 1, arranged in tandem from the left (i.e., an upstream side of Fig. 1) to the right (i.e., a downstream side of Fig. 1) are: an in-line pre-heating coil (i.e., an in-line pre-heating means or unit) 6; a four-side hot-rolling mill (i.e., a four-side hot-rolling means or unit) 7; a water-cooled jacket (i.e., a quenching/cooling means or unit) 8; a pinch roll (i.e., a tension applying means or unit) 9; and, an in-line post-heating coil (i.e., an in-line post-heating means of unit) 10; and, a wire take-up reel 11. The pinch roll 9 is driven by a motor 9a which is combined with a torque converter provided with a speed-reduction unit.

[0023] As shown in Fig. 2, a modified cross-section steel wire W2 of an embodiment of the present invention has been heat-treated and assumes a nearly trapezoidal shape in cross section. Used in a hot-rolling operation of such a modified cross-section steel wire W2 is the four-side hot-rolling mill 7. As shown in Fig. 3, the four-side hot-rolling mill 7 is constructed of: a pair of upper and lower horizontal rolls 1, 1 adjacent to upper and lower non-parallel sides of the nearly trapezoidal cross section of the steel wire W2; and, a pair of left and right vertical rolls 2, 2 adjacent to upper and lower parallel sides of the nearly trapezoidal cross section of the steel wire W2.

[0024] Now, referring to Figs. 1 and 4, a method for producing the modified cross-section steel wire W2 will be described. First of all, in a preparatory stage of the method, a piece of rolled steel having a predetermined diameter is descaled. After that, the piece of rolled steel thus descaled is drawn into a starting material W1 of the steel wire W2 while keeping its round shape in cross section. Such a starting material W2 is then delivered to the in-hot-rolling process heating coil 6 from a pay-off reel (not shown). The starting material W1 is induction-heated using the in-hot-rolling process heating coil 6, and then delivered to the four-side hot-rolling mill 7, in which the starting material W1 is hot-rolled into the steel wire W2 assuming a nearly trapezoidal shape in cross section, as shown in Fig. 2. Immediately after completion of such a hot-rolling operation, the steel wire W2 thus hot-rolled is quenched using the water-cooled jacket 8. At this time, since the pinch roll 9 is rotatably driven at a speed slightly higher than a traveling speed of the modified cross-section steel wire W2 measured in a downstream side of the hot-rolling mill 7, the steel wire W2 is delivered from the mill 7 under tension applied by the pinch roll 9 to the following quenching stage in which the quenching operation of the steel wire W2 is performed. As described above, by quenching the steel wire W2 under tension, it is possible to obtain the steel wire W2 excellent in straightness and having been quenched. Further, since the pinch roll 9 is driven by the motor 9a combined with the torque converter provided with the speed-reduction unit, there is no fear that the steel wire W2 is exposed to excessive tension. Consequently, it is possible to prevent the steel wire W2 from varying in dimension. After that, the steel wire W2 thus quenched is heated to a tempering temperature using the in-tempering operation heating coil 10 and then tempered. Subsequent to this tempering operation, the steel wire W2 thus tempered is taken up by the wire take-up reel 11. Then, in the production of a coil spring, the modified cross-section steel wire thus taken up by the reel 11 is coiled to assume a predetermined shape.

[0025] In other words, as shown in Fig. 5, a conventional method is constructed of two steps comprising the steps of: drawing a starting material into a modified cross-section steel wire; and, quenching and tempering the steel wire thus drawn. In contrast with this, in the

present invention, both the step of drawing the starting material into the modified cross-section steel wire and the step of quenching and tempering the steel wire described in the conventional method are performed in a single step of the method of the present invention.

[0026] Incidentally, in this embodiment of the present invention, though the steel wire is subjected to a tension applied by the pinch roll, it is possible to replace the pinch roll with a capstan unit. Further, it is also possible to apply a tension to the steel wire by means of the wire take-up reel. In case that the tension is applied to the steel wire by means of the capstan unit and/or the wire take-up reel, a motor combined with a torque converter is used to drive the capstan unit and/or the wire take-up reel. As for in-line heating performed in the hot-rolling process, it is possible to realize such in-line heating through induction heating and/or direct resistance heating.

20 [EXAMPLES]

[0027] Hereinbelow, an example 1 of the modified cross-section steel wire W2 according to the present invention will be described. Fig. 6 shows the chemical composition of the example 1 of the steel wire W2 having been hot-rolled.

[0028] A piece of hot-rolled steel was drawn into a round bar, i.e., a starting material W1 of the modified cross-section steel wire W2 of the present invention, wherein the steel wire W2 assumes a nearly trapezoidal shape in cross section, as shown in Fig. 2. Fig. 7 is a Table, which illustrates the particulars of the modified cross-section steel wire W2, and, more particularly illustrates the relationship between: dimensions in cross section of the modified cross-section steel wire W2 of the example 1 which has been hot-rolled and assumes such a nearly trapezoidal shape in cross section; and, a diameter of the corresponding starting material W1 of the steel wire W2. In this example 1, a so-called "reduction of area", i.e., the percentage of decrease in cross sectional area of the drawn bar or wire was equal to approximately 0.9. Each of a plurality of the steel wires W2 each assuming a nearly trapezoidal shape but varying in dimension was subsequently subjected to a quenching and a tempering operation under tension. As for the modified cross-section steel wires W2 which is small in diameter such as ones of the 40 series, the 30 series and the 25 series, a quenching operation performed under tension according to the conventional method failed to produce a product constant in cross section since these small-diameter steel wires W2 were large in variations in cross sectional dimension. In contrast with this, in the method of the present invention, since a tension was applied to the steel wire W2 by means of the pinch roll 9 combined with the torque converter, it was possible to quench such small-diameter modified cross-section steel wire W2 under tension without a fear that the steel wire or product W2 varies in diameter.

[0029] Of a plurality of products W2 shown in Fig. 7, one of an L-60 type was employed as an example 1, which will be described hereinbelow. The product of the L-60 type assumed a nearly trapezoidal shape in cross section such as one shown in Fig. 2, wherein the shape had a height of 14.40 mm, a length in lower side of 7.10 mm, and a length in upper side of 4.70 mm. On the other hand, a round bar having a diameter of 10.80 mm was used as the starting material W1 of the steel wire W2, which had been hot-rolled and assumed the above shape in cross section. A so-called "reduction of area", i.e., the percentage of decrease in cross-sectional area of the round bar or starting material W1 of the steel wire W2 during its hot-rolling operation was 0.9059. In this example 1, variations in dimension in cross section of the modified cross-section steel wire W2 having been heat-treated was within a range of a value of equal to or less than 0.05 mm, which makes it possible to obtain the heat-treated modified cross-section steel wire W2 excellent in precision.

[0030] The heat treatment of the steel wire W2 was conducted under the following conditions: namely, the round bar or starting material W1 was heated up to its rolling temperature in a period of 7 seconds; and, the steel wire W2 was delivered from an exit side of the apparatus of the present invention at a traveling speed of 100 mm/sec. As shown in Fig. 1, a plurality of temperatures at which the individual heat treatments were conducted in the example 1 were measured at a plurality of positions comprising: an exit side ① of the in-line pre-heating coil 6; a soaking position, i.e., a downstream side ② of the in-line pre-heating coil 6, in which side ② the starting material W1 thus heated was stabilized in temperature as a whole; an inlet side ③ of the hot-rolling mill 7; an exit side ④ of the hot-rolling mill 7; an inlet side ⑤ of the water-cooled jacket 8; and, an exit side ⑥ of the in-line post-heating coil 10. Fig. 8 shows temperatures measured in the above positions of the apparatus of the present invention.

[0031] In other words, the round bar or starting material w1 of the steel wire w2 was heated to a temperature of approximately 1024 °C which is equal to or more than the Ac3 point by using the in-line pre-heating coil 6 for heating the round bar w1 prior to its hot-rolling operation. As a result, the round bar W1 had its atoms rearranged into a so-called "γ (gamma)" form. After that, by means of the four-side hot-rolling mill 7, the round bar W1 was hot-rolled into the modified cross-section steel wire W2 at a temperature of equal to or more than the Ar3 point ranging from 850 °C to 760 °C. Immediately after completion of the hot-rolling operation, the steel wire W2 was quenched at a temperature of 740 °C which is equal to or more than the Ar1 point. This made it possible for the present invention to obtain the steel wire W2 having a fine structure of martensite excellent in strength. The thus obtained steel wire W2 was heated again up to a tempering temperature of approximately 500 °C and then tempered.

[0032] Fig. 9 shows the mechanical properties of the modified cross-section steel wire W2 having been heat-treated in the example 1. In other words, the modified cross-section steel wire W2 of the L-60 type having been heat-treated under the above conditions had a large tensile strength of equal to or more than 1600 N/mm² and a large elongating rate of equal to or more than 10 %.

[0033] In addition, the modified cross-section steel wire W2 thus heat-treated was excellent in straightness and free from any small-radius bend. Consequently, in this example 1, the modified cross-section steel wire W2 thus heat-treated was formed into a coil spring. When a conventional type of the modified cross-section steel wire is formed into a coil spring or product, its product defective rate often reaches a value of 10 %. In contrast with this, the modified cross-section steel wire W2 thus heat-treated according to the present invention and formed into a coil spring had a product defective rate of substantially 0 %.

[0034] Although the other types of heat-treated modified cross-section steel wires W2 shown in Fig. 7 were hot-rolled, any one of them was excellent in accuracy in dimension since they varied in cross-sectional dimension within a range of equal to or less than 0.05 mm. In addition to the above, the mechanical properties of the other types of the steel wires W2 are also shown in Fig. 7, as an example. As is clear from Fig. 7, the other types of the steel wires W2 were also excellent in each of straightness, tensile strength and elongation rate, as is in the example 1. Consequently, all the other types of the modified cross-section steel wires W2 of the present invention were found to be substantially free from any defect since any one of these steel wires W2 of the present invention had a product defective rate of substantially 0 % when formed into a coil spring, i.e., product, as is in the example 1.

[0035] In the above examples including the example 1, the round bar W1 was hot-rolled into the modified cross-section steel wire W2 and further formed into the coil spring, which was estimated and confirmed in effect of the present invention. Further, it is possible to apply the present invention to the steel wire W2 having, in cross section, not only the nearly trapezoidal shape but also other shapes such as a square shape or a rectangular shape in cross section of the steel wire W2. In application, the present invention is also applicable to not only the coil spring, but also other types of wire products such as a torsion bar and like linear products since the steel wire W2 of the present invention is excellent in straightness, which permits the method of the present invention to reduce the number of necessary process steps of the method of the present invention for producing such linear products each constructed of the modified cross-section steel wire W2 having been heat-treated, so that the production yield in the method of the present invention can be improved greatly. It is also possible to apply the present invention to various application fields other than the wire springs.

INDUSTRIAL APPLICABILITY:

[0036] As described above, according to the method of the present invention for producing the modified cross-section steel wire W2 having been heat-treated, it is possible to rapidly heat each of the round bar W1 and the steel wire W2 to a predetermined temperature in a very short period of time by using induction heating and the like. Consequently, it is possible for the method of the present invention to avoid occurrence of a problem of decarbonization which often occurs in heating in an ordinary furnace and the like. Further, in the method of the present invention, since the hot-rolled steel wire W2 of the present invention is quenched immediately after completion of its hot-rolling operation, it is possible to produce the hot-rolled modified cross-section steel wire W2 through a single process step. The above quenching operation is followed by a rapid heating and a tempering process step, which makes it possible to produce the modified cross-section steel wire W2 excellent in strength.

[0037] In the method of the present invention: the round bar W1 is rapidly heated to a tempering temperature of equal to or more than the Ac3 point; the thus heated round bar W1 is then hot-rolled into the modified cross-section steel wire W2 at a rolling temperature of equal to or more than the Ar3 point; immediately after completion of such hot-rolling operation, the thus hot-rolled steel wire W2 is directly quenched at a temperature of equal to or more than the Ar1 point by using the quenching/cooling means or unit 8, so that the steel wire W2 having a tensile strength of equal to or more than 1600 N/mm² is produced. Further, in the apparatus of the present invention, the in-line post-heating means or unit 10 for heating the thus quenched steel wire W2 to a tempering temperature is disposed in a downstream side of the quenching/cooling means or unit 8 in tandem, which makes it possible to have the quenching and the tempering operation conducted in a continuous manner in the method of the present invention.

[0038] Further, in the method of the present invention, since the round bar W2 is hot-rolled into the modified cross-section steel wire W2 using the hot-rolling mill 7, it is possible to reduce the number of surface defects of the product such as a scratch on the surface of the product and like defects, which makes it possible to produce the product or modified cross-section steel wire W2 excellent in smoothness in surface. In contrast with this, a product produced through a conventional cold-drawing process is poor in smoothness in surface. Further, it is also possible for the method of the present invention to produce a product made of high alloy steel which is difficult to be cold-drawn through the conventional process.

[0039] Still further, in the method of the present invention, since the steel wire W2 having been hot-rolled is subjected to the quenching process under tension, the modified cross-section steel wire W2 of the present in-

vention having been heat-treated is free from any defect such as a wave, a twist and/or a slight or small-radius bend in shape, and therefore excellent in straightness in shape. The tension is applied to the steel wire W2 in the quenching process by means of the pinch roll 9 and/or the wire-take-up reel and/or the capstan unit, any variation in tension does not appear in the steel wire W2. Therefore, the modified cross-section steel wire or product of the present invention is substantially free from any variation in its cross-sectional dimension, This is one of characterized features of the present invention. The effect of the present invention is large particularly as to one of the modified cross-section steel wires W2, which one has a small diameter. Due to this, an effective quenching process for quenching the small-diameter ones of the modified cross-section steel wires W2 is realized by the method of the present invention. In contrast with this, such an effective quenching process is not realized in the prior art.

[0040] Although the pre-heating of the round bar W1 is conducted by induction heating, it is also possible for the method of the present invention to employ any other heating process such as a direct resistance heating process and the like. It is also possible to employ both the induction heating and the direct resistance heating process at the same time. Further, though a single stand of the four-side hot-rolling mill 7 is employed in the above embodiment of the method of the present invention, it is also possible for the method of the present invention to employ two or more stands of the hot-rolling mills 7. Still further, though the modified cross-section steel wire W2 having been heat-treated assumes a nearly trapezoidal shape in cross section in the embodiment of the present invention, it is also possible for the steel wire W2 of the present invention to assume any other shape such as a square shape, a rectangular shape, or like shape in cross section.

[0041] As described above, according to the modified cross-section steel wire W2 having been heat-treated and the method of the present invention, it is possible to produce the heat-treated modified cross-section steel wire W2 of the present invention excellent in both straightness and strength through a single process step. Due to this, it is possible for the present invention to produce the product or coil spring which is substantially free from any defect such as ones resulted from the small-radius bend of the steel wire W2, which makes it possible to have the product defective rate reduced to a level of substantially 0 %, and therefore possible to considerably reduce the manufacturing cost of the product or coil spring which is constructed of the modified cross-section steel wire W2. Particularly, the present invention is effective in production of the small-diameter modified cross-section steel wire W2 having been heat-treated. Further, it is also possible to apply the present invention to any other application field such as one of a torsion bar constructed of the modified cross-section steel wire W2.

Claims

1. A modified cross-section steel wire having been heat-treated, **characterized in that:** a starting material of said steel wire is rapidly heated to a hot-rolling temperature in a short period of time using an induction heating means and/or directly using a resistance heating means, hot-rolled into a modified cross-section steel wire having a predetermined shape in cross section and then quenched immediately after completion of its hot-rolling operation.
2. The modified cross-section steel wire having been heat-treated as set forth in claim 1, wherein said modified cross section steel wire assumes, in cross section, either a square shape, a rectangular shape or a nearly trapezoidal shape.
3. A method for producing a modified cross-section steel wire having been heat-treated, comprising the steps of: rapidly heating a starting material of said steel wire to a hot-rolling temperature in a short period of time using an induction heating means and/or directly using a resistance heating means; hot-rolling said starting material thus heated into a modified cross-section steel wire having a predetermined shape in cross section; and, quenching said modified cross-section steel wire immediately after completion of its hot-rolling operation.
4. The method for producing the modified cross-section steel wire having been heat-treated as set forth in claim 3, wherein said starting material is hot-rolled using a four-side hot-rolling mill.
5. The method for producing the modified cross-section steel wire having been heat-treated as set forth in claim 3, wherein: said starting material of said steel wire is rapidly heated to a temperature of equal to or more than the Ac3 point in a short period of time, and then hot-rolled at a temperature of equal to or more than the Ar3 point into said modified cross-section steel wire having said predetermined shape in cross section using a hot-rolling mill; and, said modified cross-section steel wire thus hot-rolled is quenched immediately after completion of its hot-rolling operation at a temperature of equal to or more than the Ar1 point using a quenching/cooling means disposed adjacent to said hot-rolling mill in a tandem manner.
6. The method for producing the modified cross-section steel wire having been heat-treated as set forth in claim 3, wherein said modified cross-section steel wire is quenched immediately after completion of its hot-rolling operation under tension applied to said steel wire.
7. The method for producing the modified cross-section steel wire having been heat-treated as set forth in claim 6, wherein said tension applied to said modified cross-section steel wire using either a pinch roll, a wire take-up reel or a capstan unit each of which serves as a drive unit, said drive unit being provided with a torque converter for absorbing variations in tension of said steel wire.
8. The method for producing the modified cross-section steel wire having been heat-treated as set forth in claim 3, wherein, after completion of the quenching operation of said modified cross-section steel wire, said steel wire is continuously heated to a tempering temperature using an induction heating means to perform a tempering operation of said modified cross-section steel wire.
9. The method for producing the modified cross-section steel wire having been heat-treated as set forth in claim 8, wherein said modified cross-section steel wire having been heat-treated has a tensile strength of equal to or more than 1600 N/mm².
10. The method for producing the modified cross-section steel wire having been heat-treated as set forth in any one of claims 3 to 9, wherein said modified cross-section steel wire having been heat-treated assumes, in cross section, either a square shape, a rectangular shape or a nearly trapezoidal shape.
11. An apparatus for producing a modified cross-section steel wire having been heat-treated, comprising: an in-line pre-heating means for heating a starting material of said modified cross-section steel wire to a hot-rolling temperature using an induction heating means or directly using a resistance heating means; a hot-rolling means for hot-rolling said starting material into a modified cross-sectional steel wire having a predetermined shape in cross section; a quenching means for quenching the thus hot-rolled modified cross-section steel wire under tension applied thereto; and, a tension applying means for applying a tension to said modified cross-section steel wire thus hot-rolled, wherein all said means are arranged in a tandem manner.
12. The apparatus for producing the modified cross-section steel wire having been heat-treated as set forth in claim 11, wherein said hot-rolling means is constructed of a four-side hot-rolling mill.
13. The apparatus for producing the modified cross-section steel wire having been heat-treated as set forth in claim 11, wherein said tension applying means is constructed of either a pinch roll, a wire take-up reel or a capstan unit each driven by a drive unit provided with a torque converter for absorbing

variations in tension appearing in said steel wire.

14. The apparatus for producing the modified cross-section steel wire having been heat-treated as set forth in claim 11, wherein: disposed behind said quenching means in tandem is an in-line post-heating means for heating said steel wire to a tempering temperature.

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FIG. 1

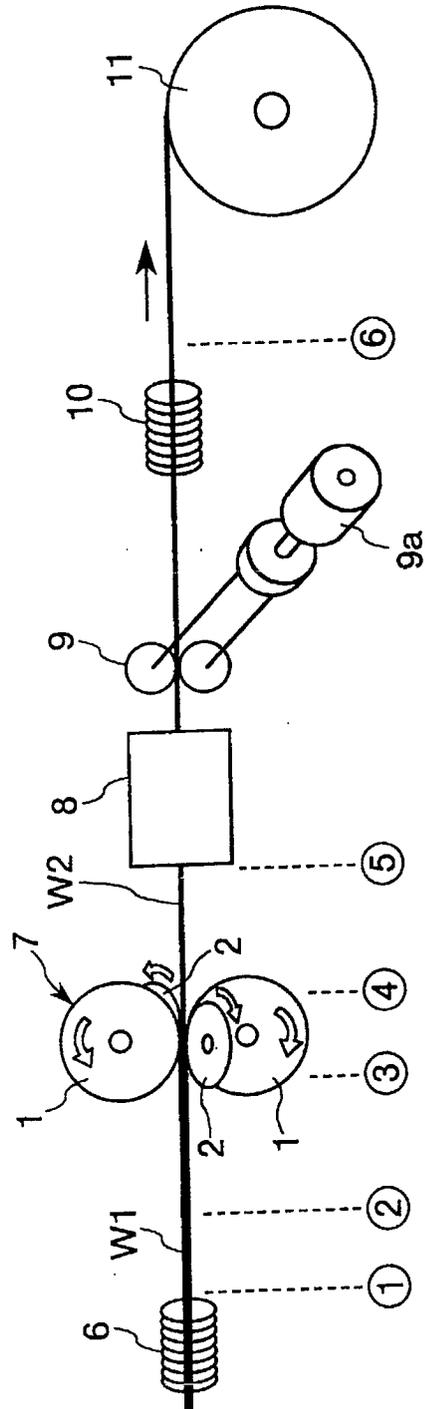


FIG. 2

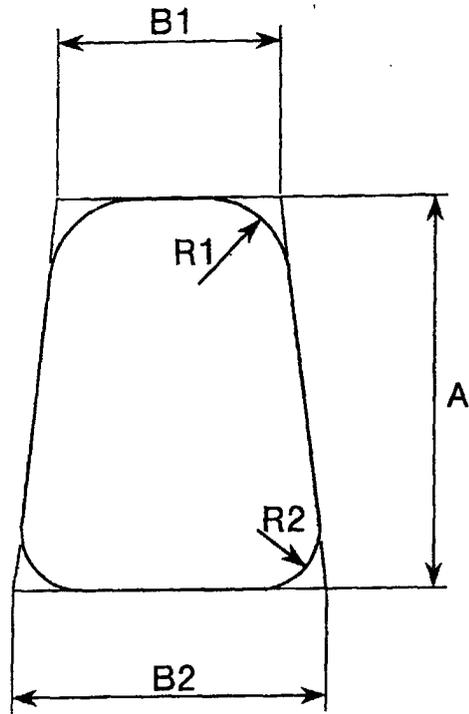


FIG. 3

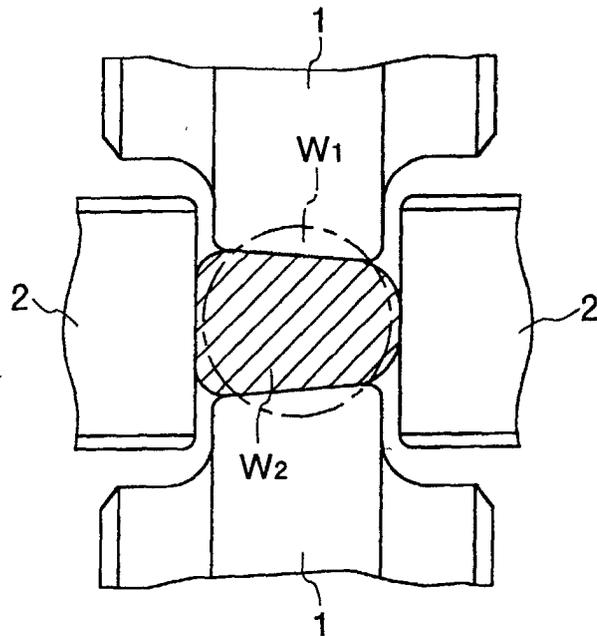


FIG. 4

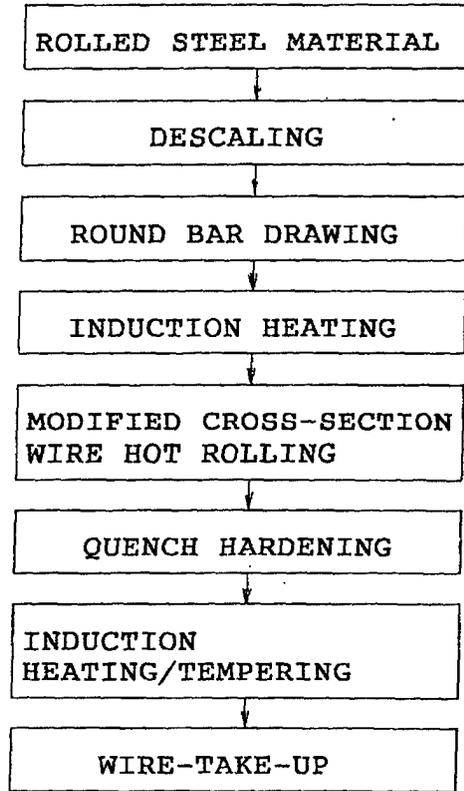


FIG. 5

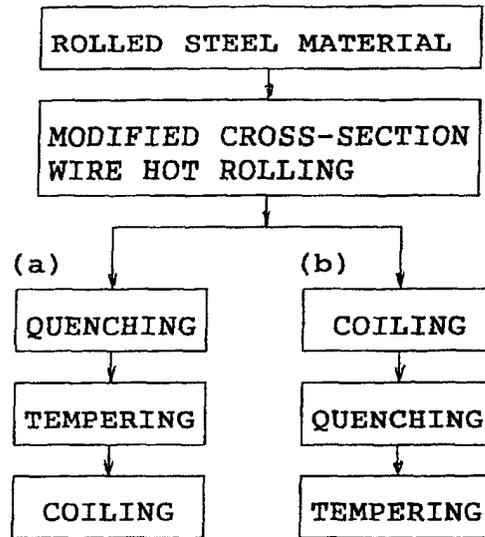


FIG. 6

C	Si	Mn	P	S	Cr
0.58	1.36	0.73	0.015	0.007	0.71

FIG. 7

PRODUCT TYPE	MATERIAL DIAMETER	PRODUCT DIMENSIONS					REDUCTION OF AREA	MECHANICAL PROPERTIES	
		A	B1	B2	R1	R2		HARDNESS (HRC)	TENSILE STRENGTH (N/mm ²)
B-60	14.70	14.55	13.10	9.40	2.60	3.30	0.9217	42.6	1282
H-60	13.50	14.40	10.90	7.90	2.30	2.80	0.9076	48.6	1553
M-60	11.90	14.50	8.30	6.05	1.75	2.10	0.9076		
L-60	10.80	14.40	7.10	4.70	1.42	1.65	0.9059	51.3	1654
F-60	9.40	12.90	5.50	4.20	1.20	1.50	0.8796	49.5	1668
B-50	12.30	12.00	10.90	8.10	2.25	2.90	0.9130		
H-50	11.30	12.00	9.30	6.70	1.90	2.80	0.9119	51.9	1783
M-50	10.00	12.00	7.10	5.10	1.50	1.80	0.9029	49.3	1665
L-50	9.00	12.00	5.55	4.15	1.20	1.45	0.8917	49.5	1661
F-50	7.80	10.80	4.65	3.55	0.95	1.78	0.8706	49.0	1652
B-40	9.80	9.40	8.80	6.65	1.80	2.60	0.9099		
H-40	9.10	9.40	7.45	5.55	1.50	2.00	0.9004		
M-40	8.00	9.45	5.65	4.20	1.20	1.50	0.8957	49.3	1653
L-40	7.20	9.55	4.45	3.25	0.90	1.10	0.8827		
B-30	7.40	7.10	6.70	4.90	1.35	1.75	0.9110		
H-30	6.80	7.10	5.60	4.00	1.20	1.45	0.8978		
M-30	6.10	7.10	4.25	3.15	0.90	1.15	0.8689		
B-25	6.00	5.90	5.50	4.00	1.20	2.60	0.9172		
H-25	5.60	5.90	4.65	3.35	0.95	2.30	0.9054	48.9	1667

FIG. 8

TRAVEL VELOCITY mm/s	POSITION					
	COIL EXIT	SOAKING	ROLL ENTRANS	ROLL EXIT	BEFORE WATER- COOLING	TEMPERING EXIT
100	1024	951	850	760	740	508

FIG. 9

0.2%YIELD STRENGTH N/mm ²	TENSILE STRENGTH N/mm ²	YIELD RATIO %	ELONGATION %	CONTRACTION OF AREA %
1472	1614	91.2	10.6	34.5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP01/06624

<p>A. CLASSIFICATION OF SUBJECT MATTER Int.Cl⁷ B21B1/16</p>		
<p>According to International Patent Classification (IPC) or to both national classification and IPC</p>		
<p>B. FIELDS SEARCHED</p>		
<p>Minimum documentation searched (classification system followed by classification symbols) Int.Cl⁷ B21B1/00-1/46, C21D9/52-9/66</p>		
<p>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-2001 Kokai Jitsuyo Shinan Koho 1971-2001 Jitsuyo Shinan Toroku Koho 1996-2001</p>		
<p>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)</p>		
<p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2-099203 A (Daido Steel Co., Ltd.), 11 April, 1990 (11.04.90),	1-3, 6, 7, 10, 11, 13
Y	Fig. 1; page 2, lower left column, line 2 to page 3, lower	4, 12
A	left column, line 18 (Family: none)	5, 8, 9, 14
Y	JP 2000-233202 A (Kawasaki Steel Corporation), 29 August, 2000 (29.08.00), Fig. 2 (Family: none)	4, 12
<p><input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.</p>		
<p>* Special categories of cited documents:</p>		
"A"	document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier document but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed	
<p>Date of the actual completion of the international search 24 October, 2001 (24.10.01)</p>		<p>Date of mailing of the international search report 06 November, 2001 (06.11.01)</p>
<p>Name and mailing address of the ISA/ Japanese Patent Office</p>		<p>Authorized officer</p>
<p>Facsimile No.</p>		<p>Telephone No.</p>