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(54) **APPLICATION OF INDUCTION HEATING TO CONTROL SHEET FLATNESS IN COLD ROLLING MILLS**

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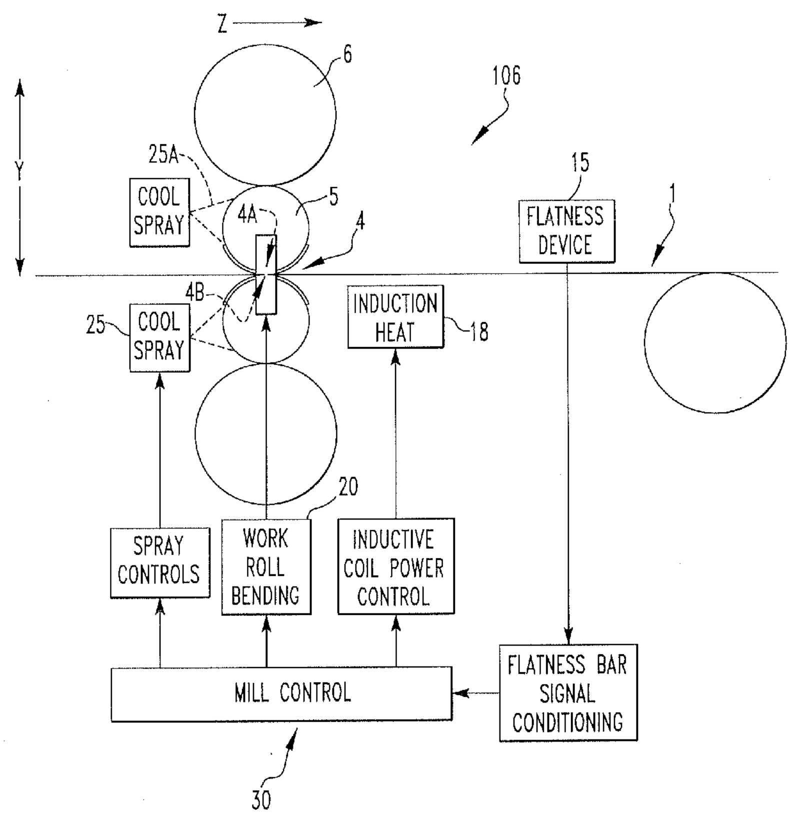
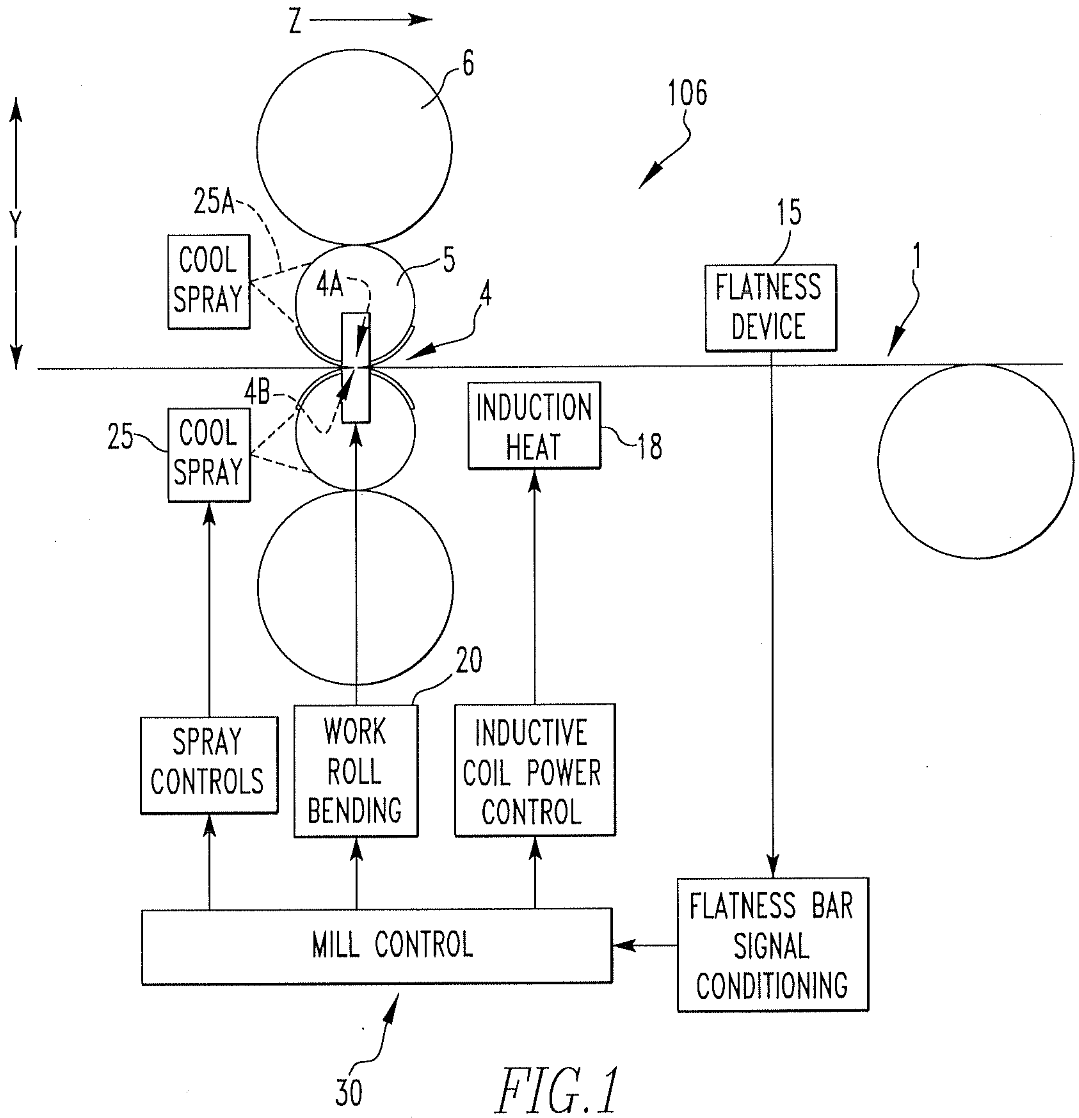
(57) **ABSTRACT**

A system for rolling metal sheet having a substantially uniform flatness including a rolling mill including a pair of work rollers for reducing the thickness of a metal sheet, an induction heating apparatus in close proximity to at least one roller, bending jacks corresponding to each of the rollers, and a cooling spray system in proximity to rollers; a flatness measuring device positioned to measure a differential in flatness of the metal sheet; and an mill control interface connected between the flatness measuring device and the rolling mill's actuators, in which the mill control interface is configured to actuate the induction heating apparatus, the bending jacks and the cooling spray system to substantially eliminate flatness differentials is the metal sheet's flatness. The induction coil heating apparatus is configured to eliminate high tension on the strip edges caused by the temperature gradients in the work rolls at the edges of the metal strip.




Z
6
106
Y
25A
COOL SPRAY
4A
5
4
15
FLATNESS DEVICE
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4B
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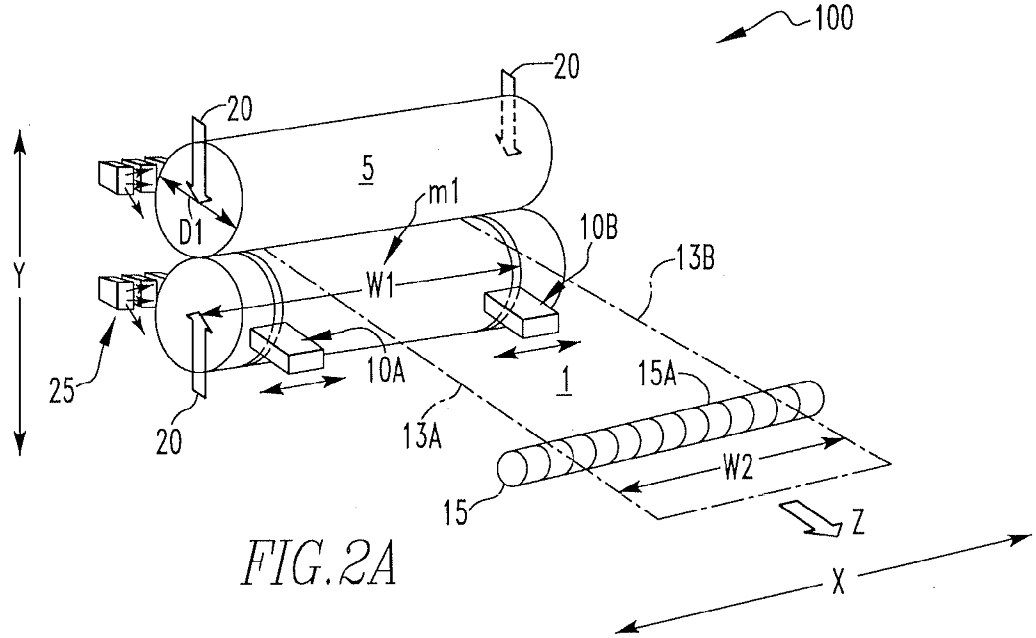
COOL SPRAY
INDUCTION HEAT
18
20
SPRAY CONTROLS
WORK ROLL BENDING
INDUCTIVE COIL POWER CONTROL
MILL CONTROL
FLATNESS BAR SIGNAL CONDITIONING
30

FIG. 1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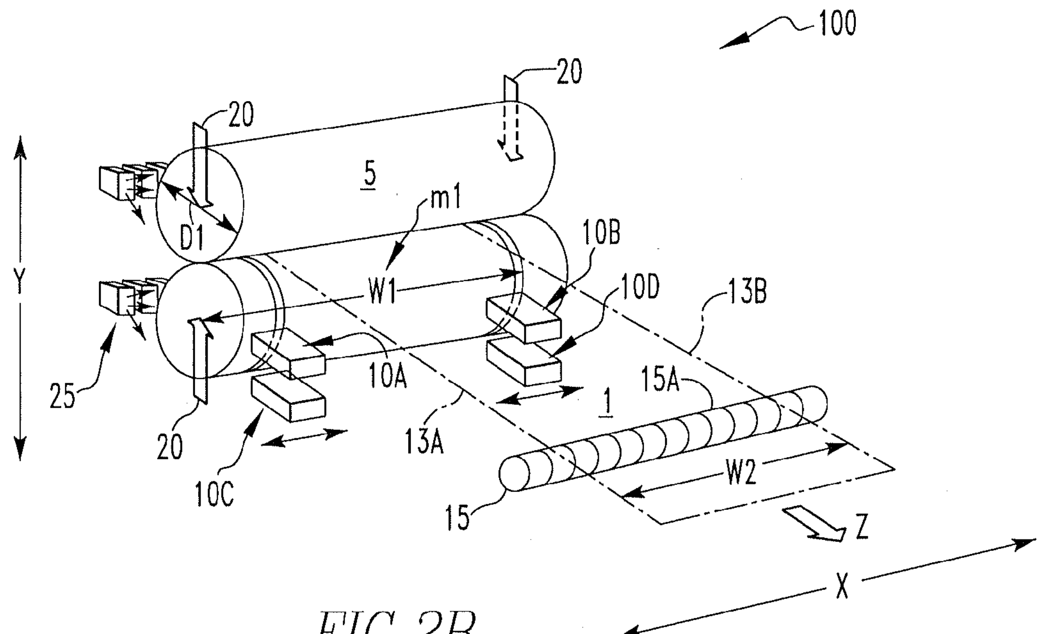
20
20
5
m1
D1
10B
13B
Y
W1
25
10A
1
15A
20
13A
W2
15
Z
X

FIG.2A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D1
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20
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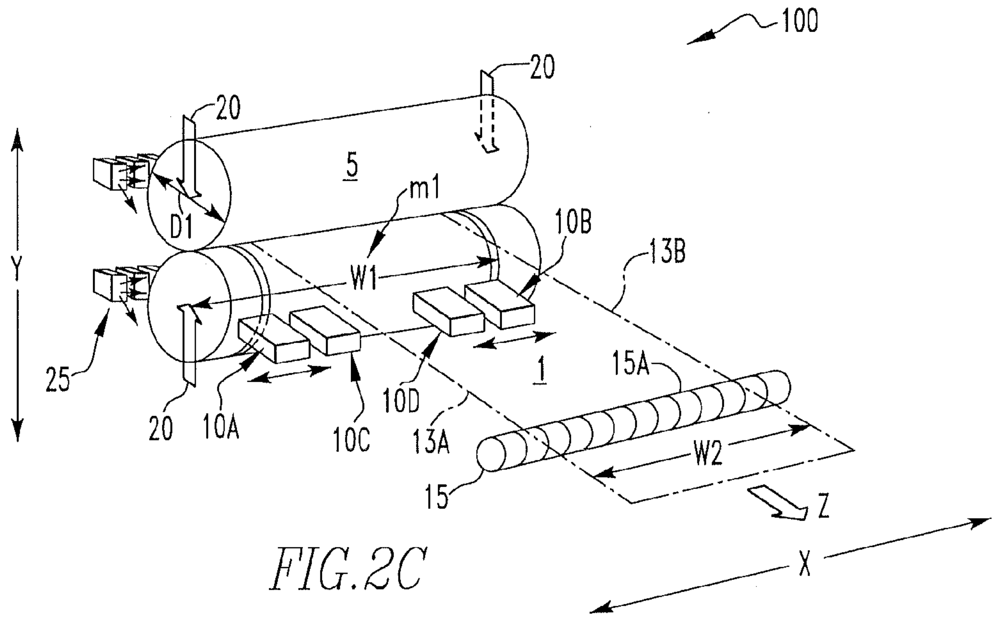
10C
W2
15
Z
X

FIG.2B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m1
10B
D1
13B
W1
Y
25
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10D
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10A
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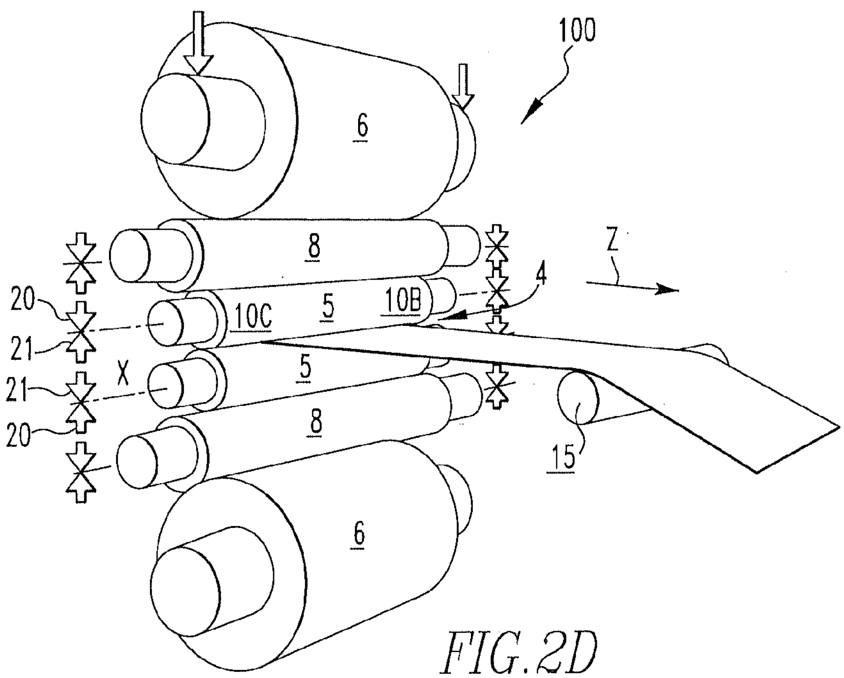
13A
W2
15
Z
X

FIG.2C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6
8
Z
4
20
10C
5
10B
21
21
X
5
20
8
15
6

FIG.2D

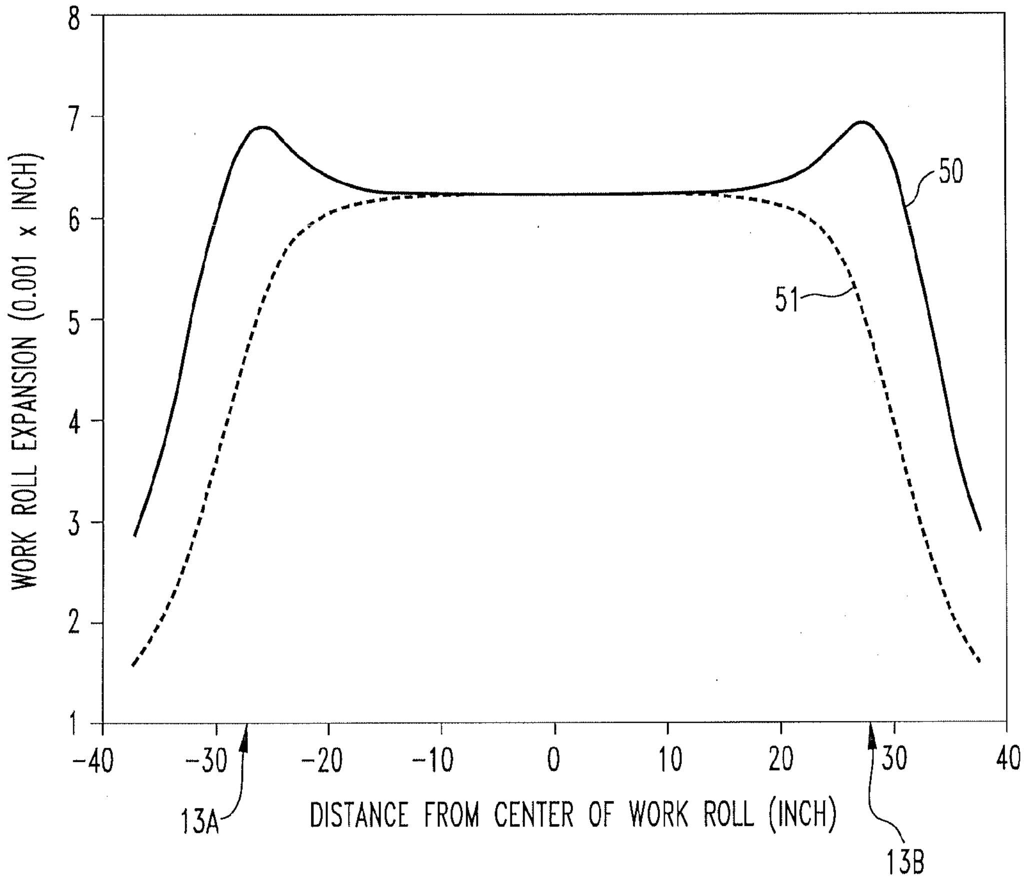
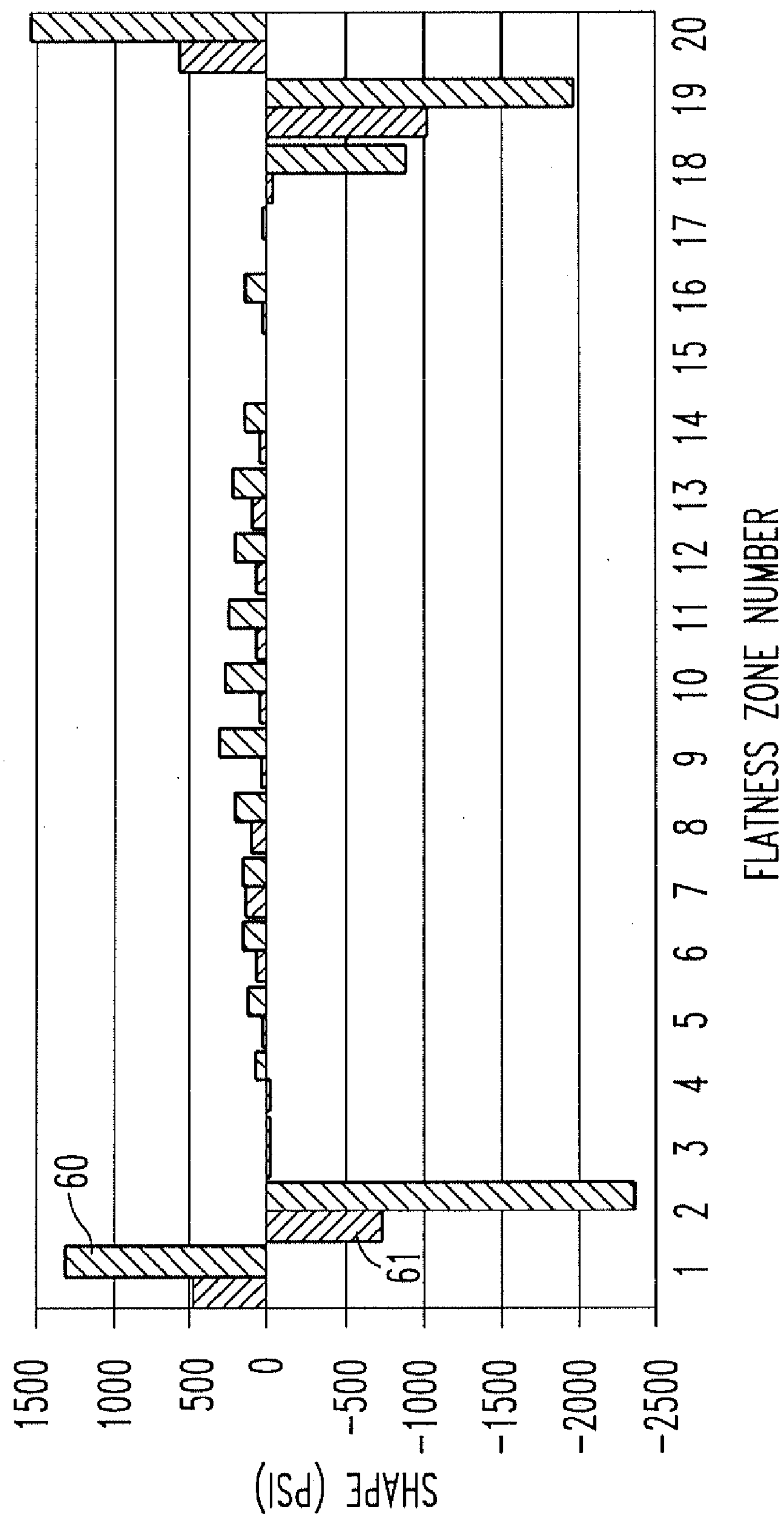

8
7
6
5
4
3
2
1
WORK ROLL EXPANSION (0.001 x INCH)
-40
-30
-20
-10
0
10
20
30
40
DISTANCE FROM CENTER OF WORK ROLL (INCH)
50
51
13A
13B

FIG. 3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-1000
-1500
-2000
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FLATNESS ZONE NUMBER
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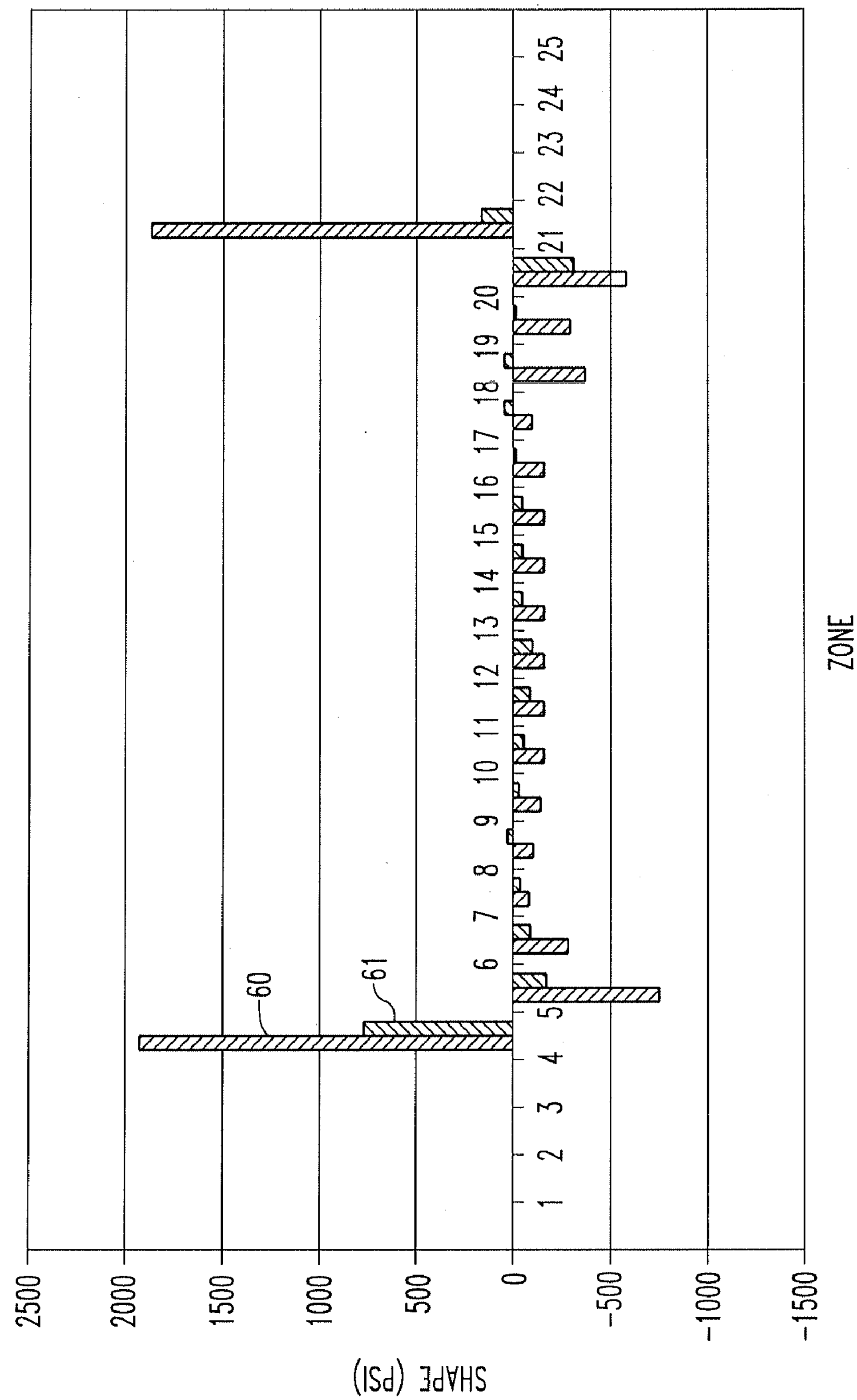
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
60
61

FIG. 4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1500
1000
500
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-500
-1000
-1500
ZONE
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5
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7
8
9
10
11
12
13
14
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61

FIG. 5

APPLICATION OF INDUCTION HEATING TO CONTROL SHEET FLATNESS IN COLD ROLLING MILLS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present invention claims the benefit of U.S. provisional patent application 60/774,974 filed Feb. 17, 2006 the whole contents and disclosure of which is incorporated by reference as is fully set forth herein.

FIELD OF THE INVENTION

[0002] In one embodiment, the invention relates to cold rolling, and a method of improving sheet flatness in cold rolled metal sheets utilizing induction heating.

BACKGROUND OF THE INVENTION

[0003] Strip products composed of metal, such as aluminum, are typically rolled in four high or six high rolling mill stands. Prior methods for forming aluminum strip have been unable to roll the strip uniformly over its entire width, and have not been able to provide rolled products being free of undesirable flatness undulations in the middle area, the edge area or the quarter area of the strip. Unevenly distributed internal stresses resulting from the material being processed with prior methods typically result in edge cracking, wherein edge cracks need to be discarded resulting in sections of the rolled product being cut away and scrapped. Edge cracking in the middle of a coil, can require that the entire coil may need to be scrapped.

SUMMARY OF THE INVENTION

[0004] Generally speaking, in accordance with the invention, in one embodiment, a method of forming metal sheet is provided that employs induction heating to thermally expand portions of the diameter of a singular work roll in response to flatness measurements taken from the metal strip downstream from the work roller. The method includes:

[0005] rolling a metal sheet between a pair of work rollers to form a rolled product;

[0006] measuring tension distribution of the rolled product from a center portion of the rolled product to at least one edge portion of the rolled product; and

[0007] adjusting a temperature in a singular roller of the pair of work rollers to provide an edge diameter of the singular roller that is greater than a center diameter of the singular work roller when the tension of the at least one edge portion of the rolled product is greater than the tension of the center portion of the rolled product.

[0008] In one embodiment, adjusting the temperature of the singular roller includes selectively heating the edge portions of the work roller to thermally expand the portions of the work roller corresponds to the longitudinal edge of the metal strip to have a greater diameter than the work roller's center portion to provide a work roller having a non-uniform diameter along its width. In one embodiment, inductive heating is employed to adjust the temperature, in which inductive heating is provided by induction heating coils that apply heat to the portions of the work rollers that correspond to the portion of the contact surface between the work roller and the longitudinal edge of the metal strip being rolled. The contact surface between the work roller and the metal strip is referred to as the working surface. In one embodiment, adjusting the temperature in the singular roller includes two induction heating coils positioned proximate to the singular work roller, wherein the heat applied by each induction heating coil is of a magnitude that adjusts the thermal expansion along a length of one of the work roller's axis such that the effect on the roll gap from the thermal crown on both rollers is fully compensated.

[0009] In one embodiment, tension measurements are provided by a flatness bar positioned downstream from the work rollers that are in contact with at least one surface of the rolled product after being rolled by the working rollers. The flatness bar may include a plurality of probes contacting the upper or lower surface of the metal sheet. In another embodiment, the tension measurements may be optically provided by methods including, but not limited to, optical scanning or laser measurements. In an even further embodiment, the tension measurements may be provided acoustically.

[0010] In another embodiment, a method for forming metal sheet includes:

[0011] rolling a metal sheet between a pair of work rollers to form a rolled product;

[0012] measuring the flatness of the rolled product; and

[0013] adjusting the diameter of a portion of a single work roller of the pair of work rollers corresponding to the longitudinal edge of the metal sheet in response to the flatness of the rolled product.

[0014] In another aspect of the invention, a system for rolling metal sheet having a substantially uniform flatness is provided. In one embodiment, the system for rolling metal sheet includes:

[0015] a rolling mill with at least a pair of work rollers;

[0016] an induction heating apparatus positioned in close proximity to a singular work roller of the pair of work rollers;

[0017] a flatness measuring device positioned downstream of the pair of work rollers; and

[0018] a mill control interface connected between the flatness measuring device and the induction heating apparatus, wherein the mill control interface is configured to receive flatness measurements from the flatness measuring device and to send signals to actuate the induction heating apparatus to provide a rolled product having a substantially uniform tension distribution across the width of the rolled product.

[0019] In one embodiment, the induction heating apparatus is configured to eliminate high tension on the strip edges that may be caused by the temperature gradient in the work rolls at the edges of the metal strip. In one embodiment, the induction heating apparatus may further include bending jacks, work roll axial sliding mechanisms and a spray cooling system, wherein the bending jacks, axial sliding mechanism and spray cooling system may also be actuated by the mill control interface in response to flatness measurements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The following detailed description, given by way of example and not intended to limit the invention solely thereto, will best be appreciated in conjunction with the accompanying drawings, wherein like reference numerals denote like elements and parts, in which:

[0021] FIG. **1** is a schematic view illustrating one embodiment of a system for controlling flatness in rolled sheet in accordance with the invention.

[0022] FIG. **2***a* is a perspective view illustrating one embodiment of a system for controlling flatness in rolled sheet including two induction heaters corresponding to a singular work roller, in accordance with the invention.

[0023] FIG. **2***b* is a perspective view illustrating another embodiment of a system for controlling flatness in rolled sheet including four induction heaters in a stacked arrangement and corresponding to a singular work roller, in accordance with the invention.

[0024] FIG. **2***c* is a perspective view illustrating another embodiment of a system for controlling flatness in rolled sheet including four induction heaters in a side by side arrangement and corresponding to a singular work roller, in accordance with the invention.

[0025] FIG. **2***d* is a perspective view illustrating one embodiment of a cold rolling mill, in accordance with the present invention.

[0026] FIG. **3** is a plot illustrating one embodiment of a work roller in which the edge portions have been thermally expanded to provide a work roller having a non-uniform diameter along the roller's width.

[0027] FIG. **4** is a graphical representation of the tension distribution of a rolled product with induction heating to the edge portions of a singular work roller, in accordance with the present invention, in comparison to a rolled product without induction heating to the edge portions of a work roller.

[0028] FIG. **5** is a graphical representation of the tension distribution of a rolled product with induction heating to the edge portions of a singular work roller, in accordance with the present invention, in comparison to a rolled product without induction heating to the edge portions of a work roller.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0029] Detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely illustrative of the invention that may be embodied in various forms. In addition, each of the examples given in connection with the various embodiments of the invention are intended to be illustrative, and not restrictive. Further, the figures are not necessarily to scale, some features may be exaggerated to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the present invention.

[0030] FIG. **1** is a schematic representation of a cold rolling system **100**, wherein the cold rolling system **100** includes at least two work rolls **5**, an induction coil heating apparatus **10***a*, and a flatness measuring device **15** configured to measure the surface flatness of a metal strip **1** being rolled by the work rollers **5**. The work rollers **5** are arranged opposed to one another, in which the gap between the work rollers **5** is referred to as the roll gap **4**. The work rollers **5** may be steel or another rigid metallic material. The sheet to be rolled is inserted between the work rollers **5** and is rolled and drawn in a direction of arrow Z. In one embodiment, the metal strip **1** is aluminum or an aluminum alloy. In one embodiment, the metal strip **1** has a thickness prior to rolling ranging approximately 0.400" to approximately 0.010". In yet another embodiment, the metal strip is an aluminum alloy that may be rolled to as thin as approximately 0.008 inch, but it is noted that even lesser thicknesses are possible, wherein the thickness of the rolled product may depend upon the rolled product's intended application.

[0031] Cold rolling denotes metal sheet processing that have cooled to room temperature, but in the course of numerous cold rolling passes of aluminum sheet the material temperature may rise to approximately 330° F. Although, the following disclosure is generally directed to cold rolling, it has been contemplated that the following method and apparatus may also be applied to hot rolling, which is within the scope of the present invention. Hot rolling of aluminum sheet is generally characterized by processing temperatures ranging from approximately 550° F. to approximately 900° F. It is noted that the above temperatures are provided for illustrative purposes only, and are not intended to limit the invention thereto, as the processing temperatures may be modified by various processing conditions, such as rolling speed, number of cold rolling passes, and the degree of cooling between rolling passes.

[0032] Referring to FIGS. **1** and **2***a*-**2***d*, during rolling inconsistencies between the profile of the roll gap **4** and the cross width thickness distribution of the metal strip **1** entering the work rollers **5** typically result in flatness defects that may be visible as wavy edges or wavy center portions of the rolled product. The cross width thickness distribution of the metal strip **1** is defined by the thickness of the metal strip measured from the upper surface of the metal strip to the lower surface of the metal strip across the metal strip's width W**1**. The roll gap profile may be defined as the dimension separating the opposing work surfaces **4***a*, **4***b* of the work rollers **5**, wherein the dimension separating the opposing work surfaces **4***a*, **4***b* of the work rollers **5** during rolling may not be uniform along the width of the work rollers **5**. The differences between the geometry of the roll gap **4** and the cross width thickness distribution of the metal strip **1** may result in inconsistencies in the elongation of the metal strip **1** across the metal strip's width W**1** following rolling that may manifest as flatness defects in the rolled product.

[0033] The mismatch or inconsistencies of the profile of the roll gap **4** and the cross width thickness distribution of the metal strip **1** that typically results in flatness defects may result from a force exerted on the work rollers **5** by the metal strip **1** being rolled, which may be referred to as bending deflections. The mismatch or inconsistencies between the profile of the roll gap **4**, and the cross width thickness distribution of the metal strip **1** that typically results in flatness defects may also result from thermal expansion of the work roller **5** that is at least partially attributed to frictional heat of the rolling process, which creates a thermal camber of the work roller **15** surfaces. The temperature in each of the work rollers **15** typically peaks at the mid point M1 of the work roller's width W1, hence the thermal expansion in each of the work rollers **5** is typically greatest at the work roller's midpoint M1 and decreases towards the edges of the rolls, which may be referred to as a thermal crown.

[**0034**] During coiling the rolled product may be pulled under tension, wherein flatness defects may manifest as tight edges, which may have a propensity to crack. The formation of tight edges at the edge portion of the metal strip being at a higher tension than the center portion of the metal strip is typically the limiting factor in the coiling speed of prior methods. It is noted that although bending jacks, coolant sprays, crowns mechanically ground into the work rollers, and work roll side shifting mechanisms may have a positive effect on reducing flatness defects in the center portions of the rolled product, such mechanisms do not provide a substantial reduction in flatness defects formed at the edge portion of the metal strip, such as the formation of tight edges.

[**0035**] In one aspect of the present invention, a substantial increase in the reduction of tight edges has been realized using an induction heating apparatus **10***a*, **10**, **10***c*, **10***d* configured to thermal expand the portions of a singular work roller of the pair of the work rollers that corresponds to the edge **13***a*, **13***b* of the metal strip **1**. The term substantially uniform tension distribution across the width of the rolled product means that when external tension is removed from the rolled product, and the rolled product is placed on a planar surface, there is substantially no lift off of the rolled product from the planar surface on which the rolled product is place. Substantially no lift off means that that lower surface of the rolled product is entirely in contact with the planar surface on which the rolled product is placed. External tension is the tension that is placed upon the sheet during coiling following rolling. In one embodiment, in order for the rolled product to be flat the longitudinal fibers across the rolled products width may be of substantially the same length in the absence of external tension.

[**0036**] Referring to FIGS. **1**-**2***d*, in one embodiment, the present invention measures flatness and the existence of flatness defects in the metal strip being rolled, such as tight edges, and in response to the measured flatness defects takes a corrective action that includes at least induction heaters corresponding to the edge portions of a singular work roller. In one embodiment, flatness measurements of the metal strip **1** are provided by a flatness measuring device **15**, that is positioned downstream of the work rollers **5** to measure the flatness of the rolled product. In one embodiment, the flatness measuring device **15** may be a flatness bar configured to measure a tension distribution of the rolled product from the center portion of the rolled product to the edge portion of the rolled product. The term "measuring a tension distribution from a center portion of the roller product to an edge portion of the roller product" means that the tension may be measured in increments from the center of the rolled product across the width of the rolled product to the rolled products edge, wherein each increment may be considered a lane longitudinally extending along the length in the direction in which the rolled product may be rolled.

[**0037**] In one embodiment, the plurality of rotors measure the cross width tension distribution across the width of the metal strip **1**. The flatness bar may include a plurality of probes contacting the surface of the metal sheet. More particularly, the rolled product is coiled under tension, wherein prior to coiling the rolled product contacts the flatness bar under which a force is induced in the y-direction upon the probes of the flatness bar, as depicted in FIGS. **2***a*-**2***c*. As discussed above, in some embodiments, the coiling tension provides a sheet that may appear to be visually flat while being coiled, but this application of external tension does not correct to the differences in elongation that manifests as flatness defects when the external tension is removed. In response to the application of external tension during coiling, a tension distribution is effected across the width W**2** of the rolled product, wherein the tension distribution in the rolled product correlates to the force induced by the sheet on each of the probes of the flatness bar. In one embodiment, the flatness bar may include a plurality of rotors **15**A, preferably having a width of 0.5" to 3.0", disposed along an arbor, wherein each of the rotors measures force along a lane corresponding to the tension of the metal strip **1** being rolled.

[**0038**] In another embodiment, the flatness of the metal sheet **1** may be optically measured or may be characterized using lasers. In yet another embodiment, the flatness measuring device may also include a non-contact system that measures the tension distribution of the metal strip using acoustical measurements. The acoustical measurements may be provided by sinusoidally modulating a vacuum under the metal strip **1**. It is noted that the above flatness measuring devices **15** are provided for illustrative purposes and that the present invention is not deemed limited thereto, since any flatness measuring device that is capable of measuring the flatness of the metal strip **1** being rolled, or determine the cross width tension distribution across the width of the metal strip **1** may be utilized and are within the scope of the invention.

[**0039**] Referring to FIGS. **1**-**2***c*, the induction heating apparatus **10** may be actuated in response to defects in the flatness or tension differentials in the metal strip **1**. Induction heating is a method by which the steel work rollers are heated by a non-contact method of using an alternating magnetic field. In one embodiment, the induction heating apparatus is composed of at least a power source which provides a power output at the required power frequency and an induction coil assembly. The power source drives a high frequency alternating electric current through the induction coil assembly. The alternating magnetic field induces a current flow in the singular work roller that may referred to as eddy currents. The current flow through the work roller increases the temperature in the work roller **5** through joule heating. In one embodiment, each induction coil **10** may include a ferromagnetic core. The induction coil heating apparatus **10** may further include at least one cooling passage for providing a cooling liquid or may not include cooling passages.

[**0040**] In one embodiment, the current through the electrically conductive coil may be on the order of about 80 amps to about 200 amps. In one embodiment, the power supply to the induction heaters has a fixed operating frequency, wherein the frequency of the electrical current signal sent to the heating coil is about 20 KHz. The current wave to the induction heater is sinusoidal with varying amplitude. Power to the induction heaters is adjusted by changing the amplitude of the sinusoidal current wave over a set number of cycles in a repeating pattern. The duration of the repeating pattern is about 8 cycles of the operating waveform. At full power, the current signal is a 20 KHz sinusoidal wave with constant amplitude. It is noted that the above currents and frequencies are provided for illustrative purposes and are not intended to limit the present invention, as other currents and frequencies have been contemplated and are within the scope of the present invention. Further, other modes of providing power have also been contemplated and are within the scope of the present invention.

[0041] In one embodiment, adjusting the temperature of the singular work roller includes induction heating coils **10** to induce heating in the portions of the work roller **5** adjacent to the work surface corresponding to the metal strip edges **13***a*, **13***b*. More specifically, the induction heating coils **10***a*, **10***b*, **10***c*, **10***d* are aligned with the portion of the work roller that contacts the longitudinal edge **13***a*, **13***b* of the metal strip being rolled to provide the rolled product, wherein the longitudinal edge **13***a*, **13***b* extends along the rolling direction. Referring to FIG. **2***a*, in one embodiment, adjusting the heat generated by the induction heating apparatus in the singular work roller includes one induction heating coil **10***a*, **10***b* positioned at each end of the roller **5**, wherein each induction heating coil **10***a*, **10***b* corresponds to each edge of the metal strip **1**. In another embodiment, adjusting the heat generated by the induction heating apparatus in the singular work roller **5** includes two induction heaters **10***a*, **10***b* corresponding to each edge **13***a*, **13***b* of the metal strip **1**, wherein the positioning of the induction coils are in a stacked configuration that may correspond to the circumference of the work roller, as depicted in FIG. **2***b*. In an even further embodiment, the induction heating apparatus may include two coils corresponding to each edge **13***a*, **13***b* of the metal strip **1**, wherein the coils are positioned adjacent to one another, as depicted in FIG. **2***c*.

[0042] In one embodiment, each induction coil **10** may correspond to the portion of the work roller **5** adjacent to the work roller's contact surface at which the metal strip **1** is being rolled, which may also be referred to as the working surface. In another embodiment, each induction coil **10** may be disposed laterally in a direction parallel to the roller's axis of rotation to reposition the coils to or near the edges of each strip. By providing induction coils **10** that may be laterally disposed the position of the induction coils may be positioned to account for metal strip's having different widths. In addition to providing that each induction coil may be disposed laterally, the induction coils may also include a mechanism to set the gap between the induction coil and the work surface of the work roll. In one embodiment, a hydraulic cylinder with a position control moves the induction coil forward until contact with roll is made and then backs off of the roll work approximately 3 mm. It is noted that other dimensions for the gap separating the induction coil from the work roll have also been contemplated and are within the scope of the present invention, so long as the degree of separation allows for effective coupling of the magnetic field from the coil to the roll so eddy currents are induced in the roll.

[0043] In one embodiment, the induction heaters **10***a*, **10***b*, **10***c*, **10***d* provide a sufficient heat to thermally expand the diameter of a singular work roller corresponding to the edge of the metal strip to be greater than the diameter of a center portion of the singular roller. The term "singular work roller" denotes one work roller of the pair of work rollers **5**, wherein the singular work roller may be either the upper or lower work roller of the pair of work rollers. The term "edge diameter of the singular roller" means the diameter of the portion of the singular roller corresponding to the longitudinal edge **13***a*, **13***b* of the metal sheet. The term "center diameter of the singular work roller" denotes the diameter of the portions of the roller between each edge diameter of the singular roller.

[0044] In the embodiments of the present invention in which the induction heat coils are positioned relative to a singular work roller of the pair of work rollers, the energy applied by the induction heating coils to increase surface temperature is of a magnitude that may provide increased thermal expansion at the section of the work roller adjacent to the metal strip's edges **13***a*, **13***b* relative to the thermal expansion of the central section of the work roller. FIG. **3** pictorially represents the effect of induction heating on the singular work roller **5** to increase the singular roller's edge diameter corresponding to the longitudinal edge **13***a*, **13***b* of the metal strip **1**, wherein reference line **50** represents the thermal expansion across the width **W1** of the singular work roller being heated by induction heating, in accordance with the present invention, and reference line **51** represents the thermal expansion along the width **W1** of the opposing roller that is not being heated by induction heating. The degree of thermal expansion is directly correlated to the temperature of the roller, wherein portions of the roller having higher temperatures have a higher degree of thermal expansion.

[0045] In one embodiment, the degree of thermal expansion in the singular roller **50** is selected to compensate for the thermal expansion **51** in the opposing rolling that does not include induction heaters. More specifically, as depicted by reference line **50**, the increased thermal expansion in the sections of the work roller **5** that are adjacent to the longitudinal edge **13***a*, **13***b* of metal strip in the work roller having induction heating coils offsets the decrease in thermal expansion in the sections of the work roller adjacent to the metal strip of the opposed work roller that does not induction heating coils, wherein the decrease in thermal expansion may be referred to as a roll off effect. The combination of the increased thermal expansion at the edge of the strip in the singular work roller and the normal roll-off at the edge diameter of the opposing work roller presents the equivalent of a uniform roll gap to the strip being deformed across its width and results in a strip having uniform flatness substantially free of tight edges upon exiting of the rolling mill stand. More specifically, the thermal expansion in the edge diameter of the singular work roller is selected to compensate for the opposing roller that has a greater diameter at the opposing roller's center in comparison to the opposing roller's edge diameter. In one embodiment, the change of dimension in the edge diameter of the singular work roller may be on the order of about 0.005 inch, in which greater and lesser degrees of expansion have been contemplated, since the degree of thermal expansion required to correct flatness defects may be effected by process conditions that include, but is not limited to, the rolling speed, rolled product material selection, the degree of heat provided by the induction heating apparatus, as well as the degree of coolant applied to the center portion of the work roller.

[0046] Referring to FIG. 1, the rolling mill 100 may also include a cooling spray system 25 in close proximity to the portion of the work rollers 5 that are in contact with the metal strip 1 being rolled. The cooling spray system 25 may spray a cooling liquid 25A at the portion of the work rollers 5 that contacts the metal strip 1, wherein the cooling liquid removes a portion of the heat generated by the rolling of the metal strip 1 in the work rollers 5. Removing the heat generated in the work rollers 5 by the rolling of the metal strip 1 through cooling spay systems cannot by themselves reduce the buildup of a thermal crown that contributes to flatness defects and tight edges.

[0047] Referring to FIG. 1, in addition to adjusting the heat generated in the work rollers 5, the differential in the sheet flatness of the rolled product may be further reduced by mechanical generation of a force that flexes the work rolls in a direction opposed to the roll flexing caused by the force generated by the metal strip 1 on the work roller 5 during rolling. In one embodiment, roll bending jacks 21 and/or side roll shift mechanisms may be utilized to generate an adjustment to the roll gap that compensates for the bending defects of the rolls resulting from the force generated by the metal strip on the work roller during rolling operations.

[0048] In one embodiment, the bending jacks are configured to provide a force opposed to roll flexing generated by the metal strip 1, and may be referred to as positive bending jacks 21. More particularly, the bending jacks 21 are configured to compensate for the force produced by the metal strip 1 against the surface of the work roller 5 that is in contact with the metal strip 1 during rolling, wherein the metal strip 1 produces forces on the top and bottom work rollers that causes them to flex and become bowed away from the strip.

[0049] In another embodiment, the rolling mill 100 may further include bending jacks 20 corresponding to each work roller 5, wherein the bending jack 20 may displace a portion of the work rollers 5 along the y-axis to substantially reduce the effect of the thermal crown on the metal strip 1 and along with the roll cooling sprays 25 facilitate the formation of a metal strip 1 having a substantially uniform flatness across the central portion of the strip, but leaving the outer edges of the strip under tension. These bending jacks 20 may be referred to as negative bending jacks, and flex the work roller in a direction opposed to the positive bending jacks 21.

[0050] The amount of bending jack force required and its direction is determined by the combination of the amount of flexing of the work roll 5 caused by strip force, the crown ground onto the work roll, and the amount of thermal expansion in the work roll 5.

[0051] In another embodiment, the work rollers 5 may also include a work roll side shifting mechanism (not shown) being configured to shift each roll 5 along a substantially horizontal axis, such as the x-axis as depicted in FIGS. 2a-2c. In one embodiment, the roll diameter of each of the opposing work rollers is ground to vary along its axis, wherein axially shifting the varying rolls to manipulate the roll gap 4 provides a correction factor that may be employed in response to measured flatness defects. More particularly, the opposing work rollers having varying diameters when axially shifted by work roll side shifting mechanisms provide another means for reducing the effects of thermal crowns buildup and roll bending from the strip force.

[0052] In one embodiment, a pair of backup rollers 6 may be employed in conjunction with the work rollers 5 in a configuration typically referred to as a four high rolling mill stand. The backup rolls 6 are used to support the work rolls and minimize their bending in response to the force of the strip. In a further embodiment of the present invention, a pair of intermediate rollers 8 may be disposed between the backup rollers 6 and the work rollers 5 in a configuration typically referred to as a six high rolling mill stand. The intermediate rollers also may include intermediate side shifting mechanisms and intermediate roll bending jacks.

[0053] The rolling system 100 also includes a rolling mill control interface 30 connected between the flatness measuring device 15 and the rolling mill's actuators. The rolling mill control interface 30 receives a signal from the flatness measuring device 15 representing measurements of differentials in the sheet flatness of the metal strip 1 or the tension distribution across the width of the metal strip 1. The rolling mill control interface 30 then processes and analyzes the signal in comparison with a predetermined target flatness value or tension distribution. In one embodiment, the rolling mill control interface processes the measured signals and formulates control outputs to the mill actuators based on a set of mathematical algorithms. In one embodiment, the rolling mill interface 30 includes a computer. The rolling mill control interface 30 then sends actuating signals to at least the cooling spray system 25, bending jacks 20 or induction heating coils 10 to compensate for differentials measured in the sheet flatness or cross tension distribution of the metal strip resulting in a metal strip 1 having a substantially flat surface that is substantially free of tight edges and thermal crown effects.

[0054] Although the invention has been described generally above, the following examples are provided to further illustrate the present invention and demonstrate some advantages that arise therefrom. It is not intended that the invention be limited to the specific examples disclosed.

EXAMPLES

[0055] FIG. 4 graphically depicts a tension distribution across the rolled product that is provided by induction heaters corresponding to the edge diameter of a singular work roller, in comparison to the tension distribution provided by a similiarly prepared rolled product without induction heating. Referring to FIG. 4, the vertical axis represents the tension (pounds per square inch) that is measured in the rolled product, and the horizontal axis represents the width of the rolled product, wherein tension measurements were incrementally recorded from a flatness bar in which each zone of the sheet corresponded width of the rolled product. The tension distribution recorded in FIG. 4 is normalized to the nominal coiling tension, which may be on the order of 3000 Psi. The tension distribution depicted in FIG. 4 was produced by an Aluminum Association 3003 series aluminum alloy metal strip rolled by a single stand cold rolling mill from a thickness of approximately 0.035" to 0.017" at a speed of approximately 625 ft/min. The metal strip being rolled by the cold rolling mill had a width on the order of about 52".

[0056] The tension distribution of the metal strip processed in accordance with the present invention **61**, includes thermal control with induction heaters positioned corresponding to the portions of a singular work roller corresponding to the strip edge of the singular work roller and a roll cooling spray system corresponding to at least a portion of the center portion of the work roller. The tension distribution of the metal strip processed in accordance with the present invention further included bending jacks configured to flex the work rollers in a direction to oppose the normal flexing caused by the force produced on the work roller by the metal strip. Additionally, the tension distribution of the metal strip processed in accordance with the present invention further included a flatness measuring device and a rolling mill control interface, where tension measurements taken from the flatness measuring device were analyzed by the rolling mill control interface and in response to the tension measurement correction factors were actuated in the bending jacks, roll cooling system, and induction heaters. The comparative example **60** was a metal strip that had been processed with bending jacks and roll cooling to optimize the measured flatness, but did not include induction heaters positioned corresponding to a singular work roller and directed to thermally expand the edge diameter of the work roller to be greater than the work roller's center diameter.

[0057] In the comparative example **60**, an increase in tension in excess of 1000 psi is measured in the edge portions of the rolled product, as indicated by the portions of the flatness measuring device corresponding to zone **1** and zone **20** of FIG. **4**, hence indicating the incidence of tight edges in the rolled product. The center portions of the rolled product of the comparative example **60**, as indicated by zone **3** to zone **17**, have a substantially uniform tension distribution indicating substantially no flatness defects in the center portion of the rolled product. Zones **2** and **19** are of low tension, and may be referred to as loose zones, which have a recorded tension being less than the externally applied tension, the externally applied tension including, but not being limited to, the coiling tension. The comparative example **60** indicates that although the bending jacks **20** and cooling spray system **25** reduce the effect of the thermal crown in the center portions of the work rollers **5**, the bending jacks and cooling spray system fail to reduce the incidence of tight edges and adjacent loose zone.

[0058] The effects of thermal crown may be further reduced in combination with the substantial eliminating of the incidence of tight edges by utilizing induction heating coils **10** to induce heat to a singular work roller **5** corresponding to the longitudinal edges **13***a*, **13***b* of the metal strip **1**, wherein the induced heat thermally expands the edge diameter of the work roller. In comparison to the comparative example **60**, the tension distribution **60** corresponding to the metal strip processed using induction heating in accordance with the invention, provides a decrease in the tension measured at the longitudinal edge of the rolled product to approximately 500 psi or less, as indicated by the portions of the flatness measuring device corresponding to zones **1** and **20** of FIG. **4** and substantially reduces the incidence of loose zones, such as zones **2** and **19**.

[0059] By reducing the incidence of tight edges in one aspect of the present invention the coiling speed may be increased without resulting in edge cracking. FIG. **5** depicts the tension distribution **61** of a rolled product, processed in accordance with the present invention, including thermal control by induction heaters positioned corresponding to the portions of a singular work roller corresponding to the strip edge, and a comparative example **60** not including induction heaters, wherein the coiling speed of approximately 1250 ft/min of the rolled product processed in accordance with the present invention is twice the coiling speed of the comparative example, which is 625 ft/min. Each of the rolled products depicted in FIG. **5** are composed of an Aluminum Association 6061 aluminum alloy and is processed through a two stand cold rolling mill from a thickness of approximately 0.125" to approximately 0.0226–.

[0060] Referring to FIG. **5**, in one example, the use of induction heating to thermally heat the portion of the singular roller corresponding to the longitudinal edge of the rolled product provides a tension distribution **61** that when compared to a rolled product not utilizing induction heating in accordance with the present invention allows for an increase to approximately 1250 ft/min without increasing the edge tension to a level that results from coiling at 625 ft/min without induction heating. More particularly, while the comparative example coiled at a speed of approximately 625 ft/min resulted in an edge tension on the order of approximately 2000 psi, the tension distribution of a rolled product processed using induction heating in accordance with the present invention allowed for a coiling speed of 1250 ft/min while having a measured edge tension of approximately 750 psi or less.

[0061] While the present invention has been particularly shown and described with respect to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in forms and details may be made without departing from the spirit and scope of the present invention. It is therefore intended that the present invention not be limited to the exact forms and details described and illustrated, but fall within the scope of the appended claims.

What is claimed is:

1. A method for manufacturing metal sheet comprising:

rolling a metal sheet between a pair of work rollers to form a rolled product;

measuring tension distribution of the rolled product from a center portion of the rolled product to at least one edge portion of the rolled product; and

adjusting a temperature in a singular roller of the pair of work rollers to provide an edge diameter of the singular roller that is greater than a center diameter of the singular work roller when the tension of the at least one edge portion of the rolled product is greater than the tension of the center portion of the rolled product.

2. The method of claim 1, comprising measuring the tension distribution with a flatness bar.

3. The method of claim 1, comprising measuring the tension distribution optically or acoustically.

4. The method of claim 2, comprising a flatness bar to measure the tension distribution of the sheet downstream from the pair of work rollers.

5. The method of claim 2, comprising placing at least one induction coil proximate to a portion of the singular work roller corresponding to the longitudinal edge of the metal sheet.

6. The method of claim 4, wherein each induction coil may be displaced laterally along a width of the singular work roller.

7. The method of claim 1, further comprising a cooling spray system configured to decrease a temperature in at least a center portion of the pair of work rollers.

8. The method of claim 1, further comprising bending jacks configured to compensate for a force produced by the metal strip against the work roller during rolling.

9. A method for manufacturing metal sheet comprising:

rolling a metal sheet between a pair of work rollers to form a rolled product;

measuring the flatness of the rolled product; and

adjusting the diameter of a portion of a single work roller of the pair of work rollers corresponding to the longitudinal edge of the metal sheet in response to the flatness of the rolled product.

10. The method of claim 9, wherein the diameter of the portion of the single work roller is adjusted to provide a rolled product having a substantially uniform tension distribution across the width of the rolled product.

11. The method of claim 9, comprising measuring the flatness with a flatness bar.

12. The method of claim 9, comprising inducing a magnetic field that induces eddy currents in the singular work roller.

13. The method of claim 9, comprising positioning at least one induction coil aligned to a longitudinal edge of the metal sheet.

14. The method of claim 9, comprising actuating a cooling spray system in response to the flatness of the rolled product.

15. The method of claim 9, further comprising actuating bending jacks in response to the flatness of the rolled product.

16. A system for rolling metal sheet comprising:

a rolling mill with at least a pair of work rollers;

an induction heating apparatus positioned in close proximity to a singular work roller of the pair of work rollers;

a flatness measuring device positioned downstream of the pair of work rollers; and

a mill control interface connected between the flatness measuring device and the induction heating apparatus, wherein the mill control interface is configured to receive flatness measurements from the flatness measuring device and to send signals to actuate the induction heating apparatus.

17. The system of claim 16 further comprising at least one of bending jacks, a cooling spray system, and a roll side shifting mechanism to displace the pair of work rollers in opposite directions along their horizontal axis.

18. The system of claim 17, wherein the mill control interface receives a signal from the flatness measuring device, analyzes the signal, and actuates at least one of the work roll side shifter, the bending jacks, the induction heating apparatus and the cooling spray system to provide a rolled product having a substantially uniform tension distribution across the width of the rolled product.

19. The system of claim 16 wherein the induction heating apparatus is an induction coil wound about a ferromagnetic core.

20. The system of claim 20, wherein the rolling mill is a cold rolling mill.

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