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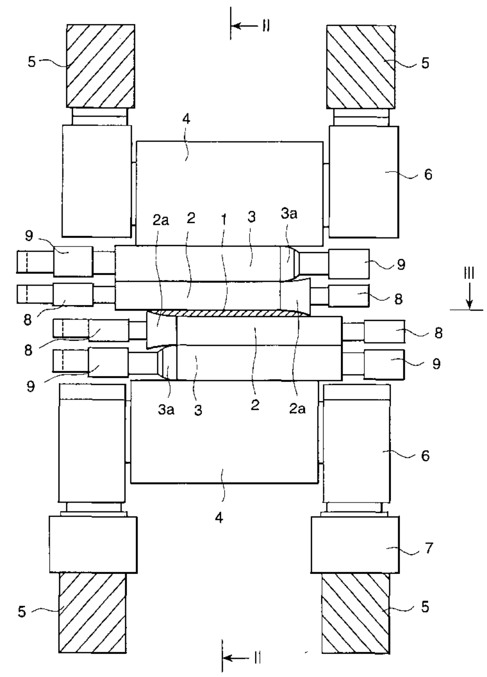
(54) A cold rolling mill and a rolling method

(57) The present invention controls the ever-changing thermal crowns to give good strip shapes during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns. A 6-high rolling mill in accordance with the present invention wherein each of the working rolls 2 which are equipped with a shifting means has a locally gradually-thickened-toward-end part (or a local concave crown 2a) on one end of the roll, the working rolls 2 are disposed so that the locally gradually-thickened-toward-end parts of the working rolls 2 may be vertically symmetrically with a point, a decremental bender lob which works to narrow the gap between the working rolls is provided as a first shape control means, both the local concave crowns 2a and the roll bender lob are used to control thermal crowns, and an incremental bender 11a which controls bending of the intermediate rolls 3 is provided as a second shape control means which controls so that the center of a strip may have a concave crown.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0001] The present invention relates to a cold rolling mill and a rolling method, more particularly, to a cold rolling mill of four-high or more-high for a reversible cold rolling facility, aluminum rolling facility, or copper rolling facility and a rolling method using said cold rolling mill.

DESCRIPTION OF PRIOR ART

[0002] In rolling of a steel strip, roll diameters will vary along the widths of the rolls due to thermal changes in the axial direction of each working roll and the resulting differences of roll expansions. This phenomenon is called a thermal crown. In other words, this is because the roll parts which the hot strip touches are heated much hotter than the other roll parts by heats caused by rolling and heats caused by frictions between the roll surfaces and the rolled strip. When this thermal crown is big, strip edges will be thicker than any other strip parts, which is called "Edge up." This makes the rolled strip have uneven thickness and reduces the yield of the rolling products. Similarly, when this thermal crown is big, the rolling tension will be greater on the strip edges or the vicinity and the strip edges are pulled too much (due to uneven tension distribution of the strip). This extremely increases the possibility of breaking the strip. Particularly, when the rolled metal is soft such as aluminum or copper, its quantity of an edge drop which is a sharp reduction of the strip thickness due to the Hertz flattening of the roll near the edges is smaller than that of general steel strips. Consequently, the thermal crown effect appears relatively greater and the rolling becomes more dangerous. Particularly in aluminum rolling which generally uses combustible rolling oil of a low flashing point, sparks due to a sheet may break ignite the rolling oil and may cause a fire. In such a state, to prevent the above problems, the rolling must be carried out carefully with the rolling speed reduced. This not only reduces the operability but also the productivity.

[0003] Similarly, the edge-up phenomenon caused by a thermal crown is also harmful to a reversible cold rolling facility which repeatedly rolls a steel strip which is supplied from and taken up by a single reel. When the reel takes up a rolled strip having its edges increased, the taken-up strip on the reel has a spool-like shape (or a built-up shape) which may easily cause skewing and loosing of the strip and consequently cause the strip surfaces to be damaged. Particularly, in the cold reversible rolling equipment, it is very hard to completely remove the rolling oil from the surface of the rolled strip. This rolling oil makes the strip on a reel slippery and uncoiled easily. Naturally, this is a great enemy to the operability and quality of rolling products.

[0004] To solve problems to be caused by thermal crowns in cold rolling, coolant controlling has been employed conventionally. Below will be explained technologies related to thermal crown controlling in both cold rolling and hot rolling together with a conventional technology related to the locally gradually-thickened-toward-end part formed on one end of each working roll in accordance with the present invention.

<Coolant control>

[0005] For example, as disclosed by "Effect of Coolant Zone Control in Shape Control During Cold Aluminum Rolling" ("Plasticity and Working" Vol.23, No.263 (December, 1982)), this technology controls the rate of cooling the rolls perpendicularly to the movement of the strip to remove the problem caused by a thermal crown. This is called "Coolant controlling." Another coolant control applies hotter coolant to the strip edges. However, these conventional coolant control technologies are not effective enough to solve problems caused by thermal crowns. Particularly, as the aluminum or copper rolling facility uses mineral coolant (oil) which is more viscous than water-soluble coolant used by a steel rolling facility, the coolant cooling is less effective to control thermal crowns in the aluminum or copper rolling facility.

<Hot rolling --- Initial concave crown on the full length of the working roll>

[0006] Such thermal crown related problems occur also in hot rolling. However, the hot rolling facility handles thicker strip (1.6 mm thick minimum) than the cold rolling facility (0.2 mm thick or under) and relatively has less influence by thermal crowns. Further, the hot rolling oil or cooling water applied to the surface of a strip to be rolled is burnt or evaporated almost completely before the rolled strip is taken up and will hardly remain on the surface of the rolled strip. Even if a slight oil will never cause slippage in strata of the coil because the strip strata of a hot-rolled material have greater frictions (e.g. due to scales on the surface of the material) than those of a cold-rolled material. Further the quality control of hot rolled materials is not severer than that of cold-rolled materials as they are frequently used as construction materials. Therefore, thermal crown controlling of the hot rolling need not be so strict. To solve the thermalcrown problems and to prevent roll abrasion, the rolling facility employs, for example, working rolls each of which is club-shaped from the center to each end of the roll to form a concave crown on the roll. Contrarily, as the cold rolling products are required to have high quality, it is very important to strictly control thermal crowns.

<Japanese Non-examined Patent Publication No.9-239411 (1997)>

[0007] In case a hot rolling facility uses high-speed-steel working rolls having excellent abrasion resistance, thermal crown controlling is very significant for the hot rolling facility because the high-speed-steel working rolls have great coefficients of linear expansion. For effective thermal crown controlling, this patent publication discloses a 4-high rolling mill having shiftable working rolls each of which increases its diameter from the center to one end of the roll (to form a half concave crown). This technology is very effective for thermal crown controlling. However, this technology is not good for cold rolling. When it is applied to cold rolling, the rolled strip is deformed and has flaws on the surface (to be explained later).

<Japanese Non-examined Patent Publication No.5-76905 (1993)>

[0008] This patent publication discloses a cold tandem rolling technology which increases the diameter of one end of each of working rolls (to give a locally concave crown) for other than thermal crown controlling. This technology is to prevent cracking in the strip edges (so-called edge cracking) which may occur in cold rolling of brittle silicon steel. This technology uses working rolls each of which has a gradually-thickened-toward-end part (increasing the diameter) on its end to form a local concave crown there in the first roll and working rolls each of which has a tapered part on its end to form a local convex crown there in the second roll and later. In other words, the working rolls in the first roll strongly presses the edges of the stripe by the local concave crowns of the working rolls to generate residual rolling stresses there and prevent the edge cracking (which may occur in cold rolling of brittle silicon steel). This strong pressing in the first roll increases the edge drop. To compensate, the second and later rolls use working rolls having locally convex crowns.

<Japanese Non-examined Patent Publication No.11-123431 (1999)>

[0009] This patent publication discloses a cold tandem rolling technology which increases the diameter of one end of each of working rolls (to give a locally concave crown) for other than thermal crown controlling. The object of this technology is to prevent generation of heat scratching and strip break in cold tandem rolling. This technology uses a pair of upper and lower working rolls each of which increases the diameter towards one end of the roll. Said pair of upper and lower working rolls are disposed symmetrically with a point and made to shift axially to load a bending force. With this, the technology cold-rolls a strip at a tension-load ratio of 0.3 or above. The shift of the working rolls is controlled to get a desired elongation at the strip edges and the bending force of the working rolls is controlled so that the strip may have a flat center. This technology enables stable rolling without a strip break and a heat scratches at a higher rolling speed.

SUMMARY OF THE INVENTION

[0010] As explained above, thermal crowns cause various problems in cold rolling. To solve such problems, a coolant control technology which controls the rate of cooling the rolls across the movement of the strip has been employed, but is not sufficient to solve the problems. Further, the thermal crown changes every moment even while an identical material is rolled and the coolant control is not quick enough to answer to such ever-changing thermal crown.

[0011] Conventionally, the ever-changing thermal crown has been controlled by a technology which gives an initial concave crown to the full length of the working rolls in hot rolling or by a technology which uses shiftable working rolls each of which increases the diameter from the center of the roll to one end of the roll to give a concave crown (half crown) as disclosed in Japanese Non-examined Patent Publication No.9-239411 (1997). These technologies change the position of the working rolls according to the change of the thermal crown to control them. However, moving the working rolls while rolling is in progress must be avoided because it may give flaws to the rolled surfaces. Particularly, it must be avoided in cold rolling, more particularly in cold rolling of soft materials such as aluminum. Further these technologies are slow in answering to the ever-changing thermal crowns.

[0012] The technologies disclosed in Japanese Non-examined Patent Publications No.5-76905 (1993) and No. 11-123431 (1999) use the working rolls each of which has an end portion thickened-toward-end (to have a local concave crown) for other than thermal crown controlling. Even if the shiftable working rolls having local concave crown are used to solve problems related to thermal crowns, problems pertaining to surface flaws and slow responsibility are left to be solved.

[0013] To control the ever-changing thermal crowns during rolling, it is assumed to be also possible to use the working rolls having a half crown or local concave crown together with a so-called roll bending technology which applies external forces to the ends of the working rolls to bend the working rolls. In this case, problems pertaining to surface flaws and slow responsibility can be solved by controlling the working roll bender according to the change of the thermal crown during rolling instead of moving the working rolls.

[0014] The difficulty in controlling the thermal crown is due to local roll deformation near strip edges by thermal expansion of the rolls. In general, it is very hard or the roll bending technology to control thermal crowns generated by such a local thermal roll deformation near strip edges. This is because the roll bending technology bends the working rolls over the full length of the rolls and cannot control the local deformation of the rolls near the strip edges.

[0015] When the ever-changing thermal crown is controlled only by the working roll bender during rolling, the crown on in the center of the rolled strip (hereinafter sometimes called a body crown) also varies greatly. Therefore, even when the working rolls are initially positioned properly, the thermal crown near the strip edges increases as rolling progresses. In this case, when the roll bender is used to control the thermal crown, the body crown changes and the strip shape becomes worse. This is because the shape of the thermal crown near strip edges does not match the shape of a crown (called an edge crown) formed by the working roll bender near the strip edges.

[0016] An object of the present invention is to provide a cold rolling mill and a rolling method which rolls strips of an even thickness in the cold state, controlling the ever-changing thermal crowns during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns

(1) To attain the above object, a cold rolling mill of 4-high or more-high in accordance with the present invention comprising first shifting equipment which can shift a pair of upper and lower working rolls in opposite directions and roll bending equipment which controls the bending of said pair of working rolls,
wherein said cold rolling mill further comprises

> locally gradually-thickened-toward-end parts provided on the working rolls at their one ends so as to be vertically symmetrical with respect to a point,
> a first shape control means for controlling a thermal crown formed on each of said pair of working rolls together with said locally gradually-thickened-toward-end parts, and
> a second shape control means for controlling to form a concave crown in the center of said rolled material.
> Said locally gradually-thickened-toward-end parts, said first shape control means, and said second shape control means work as follows. Said first shape control means controls the change of a thermal crown while a rolling is in progress and said second shape control means controls the whole shape of the rolled material which is controlled by said first shape control means (or the change of the body crown). Consequently, these means can carry out cold rolling of strips of an even thickness, controlling the ever-changing thermal crowns during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns

(2) In the above description (1), said roll bending equipment is preferably equipped with a decremental bending equipment which narrows the gap between said pair of upper and lower working rolls, and said first shape control means is said decremental bending equipment.
With this, said first shape control means can control thermal crowns during rolling without causing problems pertaining to surface flaws and responsibility to thermal crowns.
(3) In the above description (1), said roll mill is a 6-high rolling mill comprising one pair of upper and lower intermediate rolls and a second shifting equipment which can move these intermediate rolls in different directions. Said first shape control means can be said second shape control means.
With this, said first shape control means can control thermal crowns during rolling without causing problems pertaining to surface flaws and responsibility to thermal crowns.
(4) To attain the above object, a cold rolling mill of 4-highs or more in accordance with the present invention comprising first shifting equipment which can shift a pair of upper and lower working rolls in opposite directions and roll bending equipment which controls the bending of said pair of working rolls,
wherein

> each of said upper and lower working rolls has a locally gradually-thickened-toward-end part which increases in diameter toward one end of the working roll,
> said locally gradually-thickened-toward-end parts are disposed vertically symmetrical with respect to a point,
> said roll bending equipment as the first shape control means comprises decremental bending equipment which works to narrow the gap between said pair of upper and lower working rolls, and
> said rolling mill further comprises a second shape control means for controlling to form a concave crown in

the center of said rolled material.

Said locally gradually-thickened-toward-end parts, said first shape control means and said second shape control means work as follows. Said first shape control means controls the change of a thermal crown while a rolling is in progress and said second shape control means controls the whole shape of the rolled material which is controlled by said first shape control means, that is, the change of the body crown. Consequently, these means can carry out cold rolling of strips of an even thickness, controlling the ever-changing thermal crowns during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns

(4) To attain the above object, a cold rolling mill of 4-high or more-high for a cold reversible rolling facility in accordance with the present invention comprising first shifting equipment which can shift a pair of upper and lower working rolls in opposite directions and roll bending equipment which controls the bending of said pair of working rolls, wherein

each of said upper and lower working rolls has a locally gradually-thickened-toward-end part which increases in diameter toward one end of the working roll,

said locally gradually-thickened-toward-end parts are disposed vertically symmetrically with respect to a point,

said roll bending equipment as the first shape control means comprises decremental bending equipment which works to narrow the gap between said pair of upper and lower working rolls, and

said rolling mill further comprises a second shape control means for controlling to form a concave crown in the center of said rolled material.

Even when this invention is applied to a cold reversible rolling facility, said locally gradually-thickened-toward-end parts, said first shape control means and said second shape control means work as follows. Said first shape control means controls the change of a thermal crown while a rolling is in progress and said second shape control means controls the whole shape of the rolled material which is controlled by said first shape control means, that is, the change of the body crown. Consequently, these means can carry out cold rolling of strips of an even thickness, controlling the ever-changing thermal crowns during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns.

(6) To attain the above object, a cold rolling mill of 4-high or more-high for a cold aluminum rolling facility in accordance with the present invention comprising first shifting equipment which can shift a pair of upper and lower working rolls in opposite directions and roll bending equipment which controls the bending of said pair of working rolls, wherein

each of said upper and lower working rolls has a locally gradually-thickened-toward-end part which increases in diameter toward one end of the working roll,

said locally gradually-thickened-toward-end parts are disposed vertically symmetrically with respect to a point,

said roll bending equipment as the first shape control means comprises decremental bending equipment which works to narrow the gap between said pair of upper and lower working rolls, and

said rolling mill further comprises a second shape control means for controlling to form a concave crown in the center of said rolled material.

Even when this invention is applied to a cold aluminum rolling facility, said locally gradually-thickened-toward-end parts, said first shape control means and said second shape control means work as follows. Said first shape control means controls the change of a thermal crown while a rolling is in progress and said second shape control means controls the whole shape of the rolled material which is controlled by said first shape control means, that is, the change of the body crown. Consequently, these means can carry out cold rolling of strips of an even thickness, controlling the ever-changing thermal crowns during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns

(7) In the above descriptions (1) and (4) to (6), said roll mill is preferably a 6-high rolling mill comprising one pair of upper and lower intermediate rolls which can move axially. Said second shape control means comprises incremental bending equipment which controls bending of said upper and lower intermediate rolls.

With this, said second shape control means can control to form at least a concave crown in the center of the strip.

(8) In the above description (7), each of said pair of upper and lower intermediate rolls preferably have a locally tapered part on the side where the gradually-thickened-toward-end part of the working roll exists so that the tapered part may be engaged with said thickened end of each working roll and the rate of diameter changing of said tapered part is equal to or greater than the rate of diameter changing of the gradually-thickened-toward-end part.

This locally gradually-thickened-toward-end part suppresses contact pressures of the rolls from increasing and thus makes the rolls have longer service lives.

(9) In the above descriptions (1) and (4) to (6), said roll mill is a 6-high rolling mill having one pair of upper and lower intermediate rolls. Each of said intermediate rolls has a curved roll crown containing both a maximum and a minimum all over the roll and said second shape control means can be the shifting equipment which shifts said pair of upper and lower intermediate rolls in opposite directions.

With this, said second shape control means can control to form at least a concave crown in the center of the strip.

(10) In the above descriptions (1) and (4) to (6), said roll mill is a 6-high rolling mill having one pair of upper and lower intermediate rolls. Said second shape control means can have a roll-crossing mechanism which tilts at least said pair of intermediate rolls horizontally with the center of the mill approximately as the center of rotation.

With this, said second shape control means can control to form at least a concave crown in the center of the strip.

(11) In the above descriptions (1) and (4) to (6), said roll mill is a 4-high rolling mill and said second shape control means can be equipped with a roll-crossing mechanism which tilts said pair of working rolls or one pair of rolls supporting said working rolls with the center of the mill approximately as the center of rotation.

With this, said second shape control means can control to form at least a concave crown in the center of the strip.

(12) In the above descriptions (1) and (4) to (6), said roll mill is a 4-high rolling mill and each of said pair of rolls for supporting said working rolls has a roll crown which is tapered from about the center of the roll towards one end of the roll and said roll crowns are disposed vertically symmetrically with respect to a point. Said second shape control means can be equipped with the shifting equipment which can move said supporting rolls in different directions.

With this, said second shape control means can control to form at least a concave crown in the center of the strip.

(13) In the above descriptions (1) to (12), the diameter of each of said upper and lower working rolls is preferably expressed by

$$1/6Wm + 50 \leq Dw \leq 1/6Wm + 250$$

wherein

Dw is the diameter of each of the working rolls and Wm is the maximum width of a sheet to be rolled.

The decremental bending equipment used as said first shape control means to narrow the gap between said pair of working rolls can assure the effect of controlling the thermal crown.

(14) To attain the above object, a rolling method in accordance with the present invention comprises the steps of:

using shape detectors which measure the shapes of a sheet at least after being rolled and a 4-high or more-high cold rolling mill which comprises

shifting equipment which can shift one pair of upper and lower working rolls each of which has a locally gradually-thickened-toward-end part on one end of respective working rolls with the locally gradually-thickened-toward-end parts disposed vertically symmetrically with respect to a point,

roll bending equipment which controls bending of said pair of working rolls and has, as a first shape control means, decremental bending equipment which works to narrow the gap between said pair of working rolls, and a second shape control means for forming a concave crown in the center of said rolled material,

adjusting the position of said one pair of upper and lower working rolls by said shifting equipment so that side edges of the rolled sheet may be limited by said gradually-thickened-toward-end parts of said working rolls before starting rolling,

approximately fixing the shift position of said pair of upper and lower working rolls while rolling is in progress, and

determining the operations of said first and second shape control means so that their effects on the sheet may work reversely according to the output of said shape detectors.

With this, as explained in (1), said first shape control means can control the change of a thermal crown while a rolling is in progress and said second shape control means can control the whole shape of the rolled material which is controlled by said first shape control means, that is, the change of the body crown. Consequently, these means can carry out cold rolling of strips of an even thickness, controlling the ever-changing thermal crowns during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns.

(15) In the above description (14), the operation of said first shape control means is determined according to the output of said shape detector placed near the edge of the sheet and the operation of said second shape control means is determined according to the output of said shape detector placed near the center of the sheet.

This explicitly classifies the target quantities of operations of said first and second shape control means and makes actual controlling methods easier and simpler.

(16) To attain the above object, a rolling method in accordance with the present invention comprises the steps of:

using shape detectors which measure the shapes of a sheet at least after being rolled and a 6-high cold rolling mill which comprises
first shifting equipment which can shift one pair of upper and lower working rolls each of which has a locally gradually-thickened-toward-end part on one end of respective working rolls with the locally gradually-thickened-toward-end parts disposed vertically symmetrically with respect to a point,
second shifting equipment which can shift one pair of upper and lower intermediate rolls which support said working rolls reversely, and
a second shape control means for forming a concave crown in the center of said rolled material,
adjusting the position of said one pair of upper and lower working rolls by said first shifting equipment so that side edges of the rolled sheet may be limited by said gradually-thickened-toward-end parts of said working rolls before starting rolling,
approximately fixing the shift position of said pair of upper and lower working rolls while rolling is in progress, and
determing the operations of said second shifting equipment and said shape control means according to the output of said shape detectors.

With this, as explained in (1), said first shape control means can control the change of a thermal crown while a rolling is in progress and said second shape control means can control the whole shape of the rolled material which is controlled by said first shape control means, or, the change of the body crown. Consequently, these means can carry out cold rolling of strips of an even thickness, controlling the ever-changing thermal crowns during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns.

(17) In the above description (16), the operation of said second shifting equipment is determined according to the output of said shape detector placed near the edge of the sheet and the operation of said shape control means is determined according to the output of said shape detector placed near the center of the sheet.

This explicitly classifies the target quantities of operations of said first and second shape control means and makes actual controlling methods easier and simpler.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017]

FIG.1 is a vertical sectional front view of a 6-high rolling mill (a cold rolling mill) which is one embodiment of the present invention.

FIG.2 is a vertical sectional front view of the embodiment cut along the lines II to II of FIG.1.

FIG.3 is a vertical sectional front view of the embodiment cut along the lines III to III of FIG.1.

FIG.4 is a schematic view of the shape R of a thermal crown generating on a working roll relative to the center of a strip material 1 as the origin.

FIG.5 is an explanatory illustration of the dimensions of local crowns of the working rolls and the intermediate rolls and shifting of respective rolls.

FIG.6 shows the shapes of thermal crowns used for simulation.

FIG.7 shows the result of simulation of rolling by a 6-high rolling mill using straight rolls having no local crowns under conditions of certain thermal crowns.

FIG.8 shows the result of the simulation changing the working roll bending force Fw only.

FIG.9 shows the result of the simulation giving local concave and convex crowns to the end of the working rolls and the intermediate rolls.

FIG.10 shows an effect of giving a local convex crown to the ends of intermediate rolls.

FIG.11 shows the result of simulation representing the relationship between the shift position setting and the shape control characteristics to explain that controlling together with the roll benders allows loose setting of working roll positions.

FIG.12 shows an explanatory diagram for the ratio of a high-order component which that the working rolls affect the body crown.

FIG.13 shows an example of calculating the change "δCw" of the body crown, assuming the diameter of the working roll is small.

FIG.14 shows preferable ranges of working roll diameters most suitable to control thermal crowns using both the local convex crown rolls and roll benders.

FIG.15 shows a 6-high rolling mill which is another embodiment of the present invention.

FIG.16 shows a schematic sectional view of a cross-shift type 4-high rolling mill which is one of the embodiments of the present invention.

FIG.17 shows a schematic sectional view of a 6-high rolling mill which is still another embodiment of the present invention.

FIG.18 shows a schematic sectional view of a 4-high rolling mill which is a still further embodiment of the present invention.

FIG.19 is a schematic illustration of a reversible steel rolling system to which an embodiment of the present invention is applied.

FIG.20 is a schematic illustration of an aluminum rolling system to which an embodiment of the present invention is applied.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] Some embodiments of the present invention will be explained in more detail with reference to the accompanying drawings.

FIG.1 shows a vertical sectional front view of a 6-high rolling mill (a cold rolling mill) which is one embodiment of the present invention.

FIG.2 and FIG.3 respectively show sectional views of the embodiment cut along the lines II to II and III to III of FIG.1.

[0019] In FIG.1 to FIG.3, the 6-high rolling mill comprises working rolls 2 which directly touch and roll a strip material 1, intermediate rolls 3 in contact with the working rolls, backup rolls 4 in contact with the intermediate rolls 3, bearing boxes of the backup rolls 4, and a housing 5 which supports the rolls through the bearing boxes. An oil jack 7 on the bottom of the housing 5 lifts up and down the bearing boxes 6 of the backup rolls 4 to change a force to compress the strip material 1. The working rolls 2 and the intermediate rolls 3 are respectively supported by bearing boxes 8 and 9 at both ends of the rolls. Oil-pressure cylinders 10a, 10b, 11a, and 11b are provided to give forces to said bearing boxes to bend the rolls. Hereinafter, the oil-pressure cylinders 10a and 11a which bend the working rolls to enlarge the gap between the working rolls 2 are termed incremental bending equipment. The oil-pressure cylinders 10b and 11b which bend the working rolls to narrow the gap between the working rolls 2 are termed decremental bending equipment.

[0020] The working roll 2 and the intermediate roll 3 are equipped with shifting equipment which can shift the rolls 2 and 3 axially. Referring to FIG.3, an example of the shifting equipment for the working roll will be explained below. In FIG.3, the shifting equipment comprises a shift supporting member 12 which supports the bearing box 8 of the working roll 2 and a shift head 13 which is connected to the shift supporting member 12. The shift head 13 is equipped with a shift coupling means comprising hooks to easily couple the shift head with the bearing box 8 at one end of the working roll and a coupling cylinder 15. Further, the shift cylinders 16 fixed on the housing 9 are linked to the shift head. With this configuration, the working rolls 2 and the shift supporting members 12 can be moved freely by operating the shift cylinders 16 with the shift coupling means mounted. As the shift supporting member 12 contains said bending equipment 10a, 10b, 11a, and 11b, the working rolls can be shifted without changing the position of the working point of the bending force. This can increase the shift stroke.

[0021] The shifting equipment for the intermediate rolls are built up in the similar manner and is not visible in the accompanying drawings.

[0022] Each of the working rolls 2 of said 6-high rolling mill has a locally gradually-thickened-toward-end part (or a local concave crown 2a) whose diameter increases towards the end of the roll on one end of the roll. The working rolls 2 are disposed so that the locally gradually-thickened-toward-end parts of the working rolls 2 may be vertically symmetrically with respect to a point. The upper and lower working rolls are rotated in opposite directions by the shift equipment shown in FIG.3. The locally concave crowns 2a work to control thermal crowns on the working rolls 2. The length of the locally concave crown 2a is preferably equal to or greater than the thermal influence length (to be explained later) of the thermal crown (in general 100 mm to 300 mm). Further the concave crown is preferably shaped to cancel the thermal crown of the roll. Generally an approximate quadratic curve is enough. In extreme cases, the concave crown can be a tapered crown for easy roll cutting although it matches less with the thermal crown. Furthermore, said concave crown can be determined under actual rolling conditions or according to actual rolling results. Usually, the concave crown is great enough to cancel the maximum thermal crown which occurs in actual rolling and the position of the working rolls is adjusted by the shifting equipment according to the rolling conditions.

[0023] Each of the intermediate roll 3 has a locally tapered part 3a (or a locally convex crown) on the side where the gradually-thickened-toward-end part of the working roll 2 exists so that the tapered part may be engaged with the end thickened-toward-end of each working roll 2. This is provided to reduce contact surface pressures between rolls (that is, between the intermediate-roll 3 and the working roll 2 and between the intermediate roll 3 and the backup roll 4). This can suppress spalling and uneven abrasion of rolls which are apt to generate on roll ends. This can make the service life of the roll longer.

[0024] To make the description below clearer, characteristics of a thermal crown will be explained in detail. FIG.4 is a schematic view of the shape R of a thermal crown generating on a working roll relative to the center of a strip material 1 as the origin. Referring to FIG.4, the thermal crown R caused by a thermal expansion change of a roll changes gradually in an area "S" between the center of the strip and the vicinity of the strip end E, but changes dramatically in the areas "a" and "b" (before and after the strip edge). In the area "T" between the strip end and the roll end, the thermal crown R gradually changes again. The gradual thermal crown change in the area "S" can be controlled fully by a conventional roll bender or the like and it matters little. The thermal crown change in areas "b" and "T" are outside the strip and can be ignored as it will not directly give any influence to the strip. Therefore, the most-concerned thermal crown to be controlled is that in the area "a" and the quantity of a thermal crown which substantially affects the thickness of the strip us "Cs" in FIG.4. Usually, "Ch" in FIG.4 is adopted as the quantity of a thermal crown because the quantity is measured relative to the end of the roll end, assuming that "Ch" is approximately equal to 2 times of "CS." In the description below, the length of the area "a" (relative to the end of the strip) is called a thermal influence length. This thermal influence length is steadily 100 mm to 300 mm as disclosed by "Plasticity and Working" Vol.23, No.263 (December, 1982), although it is dependent upon the rolling period, rolling condition, coolant control method, etc. It is apparent that, when a strip is rolled by the working rolls having such a thermal crown, the rolled strip will have edges much thicker than any other part of the strip. (Edge-up phenomenon)

[0025] The object of the present invention is to control such a thermal crown. For that purpose, the present invention provides a locally concave crown 2a on one end of each working roll 2 as explained above.

[0026] In addition to said local convex crows 2a, the present invention provides a first shape control means which controls a thermal crown formed on the working rolls 2 together with the local convex crows 2a and a second shape control means which controls so that the strip material 1 may has at least a convex crown in the center of the strip. In the embodiments of the present invention, the first shape control means is the decremental bending equipment 10b (decremental bender) which works to narrow the gap between one pair of upper and lower working rolls and the second shape control means is the incremental bending equipment 11a (incremental bender) which works to control the bending of one pair of upper and lower intermediate rolls 3.

[0027] Below will be explained a rolling method by the rolling mill in accordance with the present invention.

[0028] To control a thermal crown by the working rolls 2 each of which has a locally concave crown 2a at the end of the roll, the working rolls 2 are shifted to a proper position according to the thermal crown which is generated. However, it is very hard to detect the thermal crown accurately while rolling is in progress. So shape detectors (see FIG.19 and FIG.20) are provided on the side of the output of the rolling mill and the output of the shape detectors are used for controlling. It is not preferable particularly in aluminum rolling to shift said working rolls 2 during rolling. Therefore it is recommendable to shift the working rolls properly when rolling is not in progress (e.g. rolling coils are exchanged) or when a slow rolling is in progress (e.g. at the exchange of rolling paths). Thanks to the effect of the local concave crowns, the influence by the thermal crown on the working rolls 2 can be reduced directly.

[0029] However, the thermal crown on the working rolls change every moment. This ever-changing thermal crown can be controlled by the first shape control means of the working roll bender, particularly, a decremental bender which controls the bending of the working rolls and the second shape control means (the incremental bender 11a for the intermediate rolls 3) which controls to give a convex crown to the strip material 1. The major point of this rolling method is to control, for example, the first shape control means to decrease the gap between the working rolls and the second shape control means to increase according to the quantity of the detected thermal crown during rolling so that the shape control means may work oppositely on the strip material. Naturally, it is needless to say that, when the thermal crown is reduced by a roll coolant control or the like, said first shape control means is controlled to increase and the second shape control means is controlled to decrease. The object of this method is to eliminate the change in the central thickness of the strip caused by the first shape control means by controlling the second shape control means to cancel the effect by the first shape control means. This enables optimum rolling without disturbing the flatness of the strip by the operation of the fist shape control means. Particularly, by determining the quantity of operation of the first shape control means according to the shape output from near the strip edges and the quantity of operation of the second shape control means according to the shape output from the center of the strip, it is possible to explicitly classify the target operation values of the first and second shape control means. This makes actual control methods extremely more comprehensive and easier. Further, to make the above control more effective, the preferable diameter of the working roll should satisfy the conditions expressed by Formula (3).

[0030] An example of simulation of controlling thermal crown shapes in rolling will be explained below under the conditions given in Table 1. This example assumes rolling of a strip of 1200 mm wide.

Table 1

Working roll diameter (mm)	Intermediate roll diameter diameter (mm)	Backup roll diameter (mm)	Roll length (mm)	Strip thickness before rolling (mm)	Strip thickness after rolling (mm)	Linear rolling Pressure (mm)
400	470	1200	1400	0.5	0.3	0.32

[0031] FIG.5 is an explanatory illustration of the dimensions of local crowns of the working rolls and the intermediate rolls and shifting of respective rolls. In FIG.5, Lcw and Lci are respectively the distance between the start of a crown and the end of the working roll 2 and the distance between the start of a crown and the end of the intermediate roll 3. Lcw and Lci are respectively 168 mm. Cw and Ci are respectively the quantity of a crown on the working roll end and the quantity of a crown on the intermediate roll end and 40 μ in quadratic curves). δw and δi are respectively the distance between the strip edge 1 and the end of the working roll and the distance between the strip edge 1 and the end of the intermediate roll.

[0032] FIG.6 shows the shapes of thermal crowns given in the present simulation. The curves A, B, and C are respectively for thermal crowns of 60μ, 50μ, and 40μ. The thermal influence length is approximately 175 mm.

[0033] FIG.7 shows the result of simulation of rolling by a 6-high rolling mill using straight rolls having no local crowns under conditions of the above thermal crowns. The horizontal axis of FIG.7 represents the distance relative to the center of the strip (in millimeters) and the vertical axis represents the thickness of the rolled strip (in millimeters). Assuming that the distance (δi) between the strip edge and the end of the intermediate roll is 0, the bending forces Fw (by the working roll bender) and Fi (by the intermediate roll bender are respectively -18 tons ("-" means "decremental") and 68 tons so that the body crown in the center of the strip may be approximately linear (flat). Curves A, B, and C in FIG.7 are respectively for thermal crowns 60μ, 50μ, and 40μ in that order.

[0034] As apparent from FIG.7, every case has an extreme increase in thickness near strip edges (called "edge-up shapes") as shown by EA of case A. Further, it is apparent that the strip thickness temporarily falls extremely just before the edge-up starts (edge 2 indicated by ES). This so-called edge 2 elongation which is locally extended near the edge 2 exerts an internal pulling force (internal tension) on the edge-up strip edges. An external force such as a tension by the take-up reel also works strongly near the edges and is added to the above internal tension. These strong forces are enemies to thin silicon steel strips (of 0.3 mm thick or under) even in the cold reversible rolling and more particularly to soft aluminum or copper strips. They may easily break the strips in rolling as already explained above.

[0035] Below will be explained whether such shapes can be improved only by adjustment of the bending force. Here, the effect which the intermediate roll bender Fi exerts on the whole width of the strip and valid to control the body crown, but not valid to control shapes which appear only near strip edges. So we simulated how the shapes are controlled by changing the working roll bender Fw only. FIG.8 shows the result of the simulation, assuming that a thermal crown is 50 u (as well as characteristic curve B of FIG.7). The characteristic curve "a" is for Fw of 14 tons and the characteristic curve "b" is for Fw of 22 tons. As for the curve "a," the edge 2 elongation decreases when the bending force Fw increases, but the edge-up shape increases. Therefore, it is apparent that the shape and the tension distribution cannot be improved by increase of Fw. Contrarily, when Fw is decreased, the edge-up shape is a little improved and the body crown becomes bigger and the strip shape is not acceptable.

[0036] Judging from the above, controlling only by the normal roll bender almost ineffective to the local irregularity near the strip edges.

[0037] Next, we simulated rolling by giving local concave and convex crowns to the end of the working rolls and the intermediate rolls. The result of the simulation is illustrated in FIG.9. In this case, the roll shifts δw and δi are respectively 14 mm and 0 mm in that order. Characteristic curves A, B, and C are respectively for thermal crowns 60μ, 50μ, and 40μ in that order. The bending forces are properly adjusted to have a good strip flatness.

[0038] As apparent from FIG.9 and FIG.7 in comparison, the edge-up shape by a thermal crown of a current interest is greatly improved. Therefore, when this example is applied to a cold reversible rolling facility or a rolling facility for soft materials such as aluminum or copper, the operability, yield, and quality of rolling products will be improved dramatically.

[0039] Referring to FIG.10, below will be explained an effect of giving a local convex crown to the ends of intermediate rolls 3. FIG.10 shows the distributions of linear contact pressures before and after local convex crowns are applied to the ends of the intermediate rolls 3, assuming a thermal crown of 50μ is applied. The curve Q indicates the distribution of linear contact pressures between the working roll 2 and the intermediate roll 3 and the curve R indicates the distribution of linear contact pressures between the intermediate roll 3 and the backup roll 4. However, the roll bending forces are a little changed to match the crown of the rolled strip with the characteristic curve B of FIG.9. FIG.9 also shows the shape of the resulting body crown S for reference.

[0040] As seen from FIG.10, when a local convex crown is applied, the peak in the linear pressure distribution on the ends of the rolls (see the curve D) is decreased greatly. So it is apparent that giving a local convex crown to the ends of the intermediate rolls 3 has the effect to suppress uneven abrasion of respective rolls and make the service lives of the rolls longer. However, it is apparent that the local convex crown of the intermediate rolls 3 are not necessary and absolute conditions judging from the shape control characteristics of thermal crowns because the resulting flatness (shapes) are almost identical. For example, in case the rolling load is small and the roll contact surface pressure is ignorable, the local convex crowns on the intermediate rolls 3 are omittable.

[0041] It is needless to say that the thermal crown changes every time even in rolling of an identical coil. For example, in rolling under constant coolant control conditions, the thermal crown is apt to increase gradually. Contrarily, when the working rolls are given local concave crowns, the position of the working rolls 2 must be controlled every time according to the quantity of thermal crowns. However, moving the working rolls during rolling may possibly give flaws to the rolled surfaces and it is not preferable to move the working rolls during rolling in the cold rolling facility, particularly in rolling of soft materials such as aluminum. It is also possible to control the thermal crowns by coolant control, but this is very slow to answer and not practical.

[0042] Therefore, the present invention uses the roll bender control method to control the change of thermal crowns in rolling. In this case, as seen from FIG.9, it is necessary to control the working roll bender to narrow the gap between rolls and the intermediate rolls to increase the gap as the thermal crown increases. In this case, if a greater local concave crown is applied to the working rolls, the working roll bender can be controlled to increase, but in this case the edge drop will increase. Therefore, it is preferable to make the local concave crown as small as possible. Further, controlling the thermal crowns by both the local concave crowns and the decremental bender can increase the yield of products greatly.

[0043] Further when the above control is accompanied by a roll bender control, the setting of the position of the working rolls 2 need not be so fine. See FIG.11 which is the result of simulation representing the relationship between the shift position setting and the shape control characteristics, using the same conditions as those for Table 1 and a thermal crown of 50μ. Curves A, B, and C in FIG.11 are respectively for roll shifts (δw) 0 mm, 14 mm, and 28 mm in that order. They are the distributions of the rolled strip thickness with the working roll bender and the intermediate roll bender adjusted properly.

[0044] As apparent from FIG.11, preferable rolling shapes can be obtained by controlling the bending forces of the working rolls 2 and the intermediate rolls 3 even when the setting position of the working rolls is changed. Contrarily the use of both the working roll bender and the intermediate roll bender enables a rough setting of the working roll positions. The above effect by the use of both roll benders is apparent and greatly simplifies the setting of the shifting position of the working rolls 2.

[0045] In this thermal crown control, the diameter of each working roll substantially has significant meanings. In other words, the body crown caused by the thermal crown can be approximately expressed by a polynominal of the fourth order or higher. Therefore, the work roll's characteristics affecting the body crown preferably have components of orders as high as possible. This means the diameter of each working roll is preferably small. However, if the diameter of the working roll is extremely small, the effect of the roll benders is limited to the strip edges and their vicinity which is smaller than the thermal influence length of the thermal crown. Accordingly, this does not have any substantial merit to control the thermal crown. Further, the small working roll diameter may disable driving of the working rolls which is required for steady rolling. This is one of significant points to be noticed in installation of a cold reversible rolling facility which rolls soft materials such as aluminum and copper. Further, if the diameter of the working roll is small, the body crown created by the working roll bender generally becomes complicated. This makes shape controlling more difficult. Contrarily, when the diameter of the working roll is great, low-order components will be predominant when the working roll bender exerts on the body crown. Therefore, when a thermal crown is controlled, the body crown is affected greatly and the control is far from the optimum one.

[0046] Judging from the above, for control of a thermal crown by both the working roll benders having local concave crowns on the ends and the working roll bender, it is apparent that the optimum diameters of the working rolls enter in a certain range. This will be explained below referring to FIG.12.

[0047] FIG.12 shows the characteristics of the working roll decremental bender exerting on the body crown, having the diameter of the working roll as the horizontal axis and the rate "r" of high-order components of the body crown as the vertical axis. "r" is expressed by

$$r = a_4 / (a_2 + a_4) \qquad (1)$$

wherein "a_2" and "a_4" are coefficients of a 4-order polynominal optimizing the change "δCw" of the body crown by the working roll bending force "δFw."

$$\delta Cw = a_4 X^4 + a_2 X^2 \quad (2)$$

wherein "x" is the X coordinate of the strip edge (±1) relative to the center of the rolling mill.

[0048] In other words, "r" is the ratio of a high-order component "a_4" to the whole amount of body crowns "$a_4 + a_2$" appearing on strip edges by the bending force "δFW." As this "r" value increases, the high-order component has a greater effect that the working roll bender exerts on the body crown. That is, a greater "r" value is best fit for thermal crown controlling. Curves A, B, and C in FIG.12 are respectively for maximum strip widths 1200 mm, 1500 mm, and 1800 mm. In this case, the rolls are respectively 1420 mm, 1720 mm, and 2020 mm long and the linear rolling pressure (load) is 0.5 ton/mm.

[0049] As apparent from FIG.12, even when the diameter of the working roll is equal to or greater than the "a" value in the figure, the high-order component fit to control a thermal crown changes little. Contrarily, it increases the rolling load and power, the size of the rolling mill, and consequently the rolling cost. For effective thermal crown controlling, it is particularly preferential to use working rolls whose diameter is equal to or greater than the "a" value given in FIG.12.

[0050] Further, when the diameters of the working rolls are smaller, the ratio "r" of the high-order component of the body crown is 1 or above. FIG.13 shows an example of calculating the change "δCw" of the body crown, assuming the diameter of the working roll is 200 mm and the maximum strip width is 1200. The solid line represents an approximate line obtained from the approximate equation of "δCw" (given in FIG.13). From FIG.13, we can see that the change "δCw" that the force "δFw" exerts on the body crown shows a complicated characteristic which makes a concave form in the center of the strip. Therefore, the approximate equation of the change of the body crown "δCw" is made so that the fourth and second order coefficients have different signs and consequently the ratio of the high-order component becomes "r" or above. If the working roll bender of a rolling mill having such characteristics is controlled to decrease, the strip edges can be thinner. The center of the strip has an effect as if the incremental bender is applied. This is a very complicated characteristic, which makes actual shape control complicated. This must be avoided. Therefore the work roll diameter must be selected so that the ratio of the high-order component may be 1 or less.

[0051] Substantially, it does not mean that the smaller roll diameter is determined only from said shape control characteristics and it is natural that the roll diameter is such as to transmit required rolling torque.

[0052] In summary, FIG.14 shows preferable ranges of working roll diameters most suitable to control thermal crowns using both the local convex crown rolls and roll benders. FIG.14 has the maximum strip width as the horizontal axis and the roll diameter as the vertical axis. The preferable working roll diameter Dw in FIG.14 is expressed by

$$1/6Wm + 50 \leq Dw \leq 1/6Wm + 250 \quad (3)$$

wherein Wm is the maximum strip width.

[0053] The embodiment of the present invention can control thermal crowns in cold rolling without causing any flaw in the rolled surfaces and any response problems, further can properly control thermal crowns which change every moment in rolling without deteriorating the whole strip shape. Thus, the present embodiment can produce steady rolled products.

[0054] Next will be explained another embodiment using the other type of rolling mill having the similar effect.

[0055] FIG.15 shows a 6-high rolling mill which is another embodiment of the present invention. This embodiment has working rolls each of which has a local concave crown at one end of the roll and the working rolls are disposed vertically symmetrically with a point. The working rolls can be shifted horizontally. Similarly the intermediate rolls 3 are straight rolls which can be shifted horizontally. When controlling a thermal crown, the working rolls 2 are shifted so that each strip edge may come on the locally convex crown 2a of each working roll 2. Further the intermediate rolls 3 are disposed so that its end may be approximately near one of the strip edges. Naturally, the upper and lower rolls 2 and 3 are disposed approximately symmetrically with a point.

[0056] From the aforesaid description, it is apparent that the rolling mill in accordance with the present invention can preferentially control thermal crowns on the local concave crown 2a of the working rolls 2 more together with the use of a working roll bender or particularly together with the decremental bender. However, as the intermediate rolls 3 have no escape for the local concave crown 2a, the linear contact pressure between rolls increases. But there is another merit to use the rolling mill of this type for thermal crown controlling.

[0057] Even when there is no thermal crown, the intermediate rolls require a basic bending force (so-called basic intermediate roll bending force) to control a body crown caused by a bending of rolls such as the backup rolls. Contrarily, the rolling mill such as that of FIG.15 can make the width of contact between the working roll and the intermediate roll approximately equal to the strip width. In other words, this can make the width of a load distributed between the working roll and the intermediate roll approximately equal to the strip width and the working rolls 2 outside the strip width undergo no extra force. Consequently, the bending of the working rolls 2 decreases. This has an effect to reduce said required basic intermediate roll bending force and further to reduce the linear contact pressure caused by the intermediate roll bender between the intermediate roll 3 and the backup roll 4.

[0058] In the description of FIG.9, we explained that the intermediate roll bending force is controlled to increase as the thermal crown increases. As said basic intermediate roll bending force is added to this intermediate roll bending force, the effect of using the rolling mill of the present structure is apparent when both the local concave crown rolls and the roll bending equipment are used to control thermal crowns. Particularly, the rolling mill of the present structure is effective for rolling of a narrow strip when the strip width range is wide (for example when the minimum strip width is 0.4 to 0.3 of the maximum strip with).

[0059] In the above embodiment description, we explained a 6-high rolling mill comprising intermediate rolls 3 which can be shifted horizontally and working rolls 2 each of which has a local concave crown at its end. We also explained that using the roll bender together is effective for controlling a change of a thermal crown in rolling. The main feature of this thermal crown controlling using bender controlling together in the 6-high rolling mill is using a working roll bender which is a first shape control means fit to control a thermal crown which generates on the working rolls 2 and a second shape control means fit to control body crowns which are caused by a bending of rolls such as the backup rolls 4. In other words, to control thermal crowns, the first shape control means is controlled to decrease and the second shape control means is controlled to increase so that the convex body crown may be suppressed and the rolled strip has an even flatness over the full width of the strip.

[0060] We have another method of controlling thermal crowns which change every moment in rolling. This method mainly comprises a step of shifting each the intermediate rolls 3 of the 6-high rolling mill having the shiftable intermediate rolls of FIG.1 away from each strip edge instead of using the working roll bender (working as the first shape control means) together to control the change of thermal crowns in rolling. With this, the end part of each intermediate roll 3 presses the local concave crown on the end of each working roll 2 and gives a local bending deformation to the end part of the working roll 2. This further presses the edges of the strip. It is needless to say that the pressing force at the strip edges can be reduced by shifting the intermediate rolls 3 towards the center of the strip. This method does not shift the working rolls during rolling and causes no flaw on the rolled surfaces. Therefore, this method can effectively control ever-changing thermal crowns.

[0061] In the above embodiments, the second shape control means of the 6-high rolling mill is an intermediate roll bender. Various methods explained below will be applicable to the second shape control means.

[0062] FIG.16 shows a schematic sectional view of a cross-shift type 4-high rolling mill which is one of the embodiments of the present invention. This rolling mill has a shifting means which can shift the working rolls 2 horizontally and a crossing means which can rotate the working rolls around the vertical center of the rolling mill. Typical crossing and shifting means are disclosed in Japanese Non-examined Patent Publication No.7-60310 (1995).

[0063] A local concave crown is formed on one end of each working roll 2. The rolling mill has at least a decremental bender or preferably both a decremental bender and an incremental bender as a first shape control means. It is publicly known that the cross-movement of the working rolls 2 can vary the gap (so-called a roll gap) between the upper and lower working rolls 2 along the width of the rolled strip almost quadratically and effective to control body crowns. Therefore, in this case, the second shape control means is the crossing means of the working rolls 2. FIG.16 shows an example of crossing the working rolls 2, but it is apparent that the similar effect is obtained by using a crossing means, as the second shape control means, which crosses only the backup rolls 4 or both the working rolls 2 and the backup rolls 4 simultaneously. Further, a 6-high rolling mills comprising intermediate rolls with a crossing means such as disclosed in Japanese Non-examined Patent Publication No.10-234512 (1998).and Japanese Non-examined Patent Publication No.2000-33405 can use the intermediate rolls crossing means as the second shape control means.

[0064] FIG.17 shows a schematic sectional view of a 6-high rolling mill which is another embodiment of the present invention. The working rolls 2 each of which has a local concave crown on one end of the roll can be shifted horizontally. The rolling mill has at least a decremental bender or preferably both a decremental bender and an incremental bender as a first shape control means.

[0065] Each of the intermediate rolls is profiled to have a tertiary curve with maximum and minimum points and shifted horizontally by a second shape control means. It is publicly known that the gap between the upper and lower working rolls 1 can be controlled substantially quadratically by shifting the intermediate rolls by said second shape control means and effective to control body crowns. However, said second shape control means has almost no effect to control local irregularities on strip edges such as thermal crowns. Thus the first shape control means is required.

[0066] FIG.18 shows a schematic sectional view of a 4-high rolling mill which is another embodiment of the present invention. The working rolls 2 each of which has a local concave crown on one end of the roll can be shifted horizontally. The rolling mill has at least a decremental bender or preferably both a decremental bender and an incremental bender as a first shape control means. The backup rolls 4 respectively have a convex crown which is gradually tapered from the center of the roll to the end of the roll and are shifted by a shifting means. It is publicly known that the gap between the upper and lower working rolls 1 can be controlled substantially quadratically by shifting the intermediate rolls 4 vertically by said second shape control means and effective to control body crowns. For example, said working rolls with said crowns and said shifting means are disclosed in Japanese Patent Publication No.2865804. In this case, the second shape control means is a shifting means for the backup rolls 4. In such a rolling mill, it is preferable that the local concave crown of the working roll 2 is matched with the convex crown of the backup roll 4. This has an effect of reducing the contact surface pressure between the working roll 2 and the backup roll 4 and an effect of eliminating inclined abrasion of rolls, which is apparent from the above description of the 6-high rolling mill.

[0067] FIG.19 is a schematic illustration of a reversible steel rolling system to which an embodiment of the present invention is applied. This rolling system comprises a rolling mill 17 in the center of the system, tension reels 19 (one each side of the rolling mill), pinch rolls 20 (one pair each side of the rolling mill), shape detectors 21 (one each side of the rolling mill), fluid cutting means 22 (one pair each side of the rolling mill), a pay-off reel which feeds the first strip material (coil) (only one side of the rolling mill), and another set of pinch rolls 20 (only one side of the rolling mill). Further, the rolling mill 17 has roll cooling headers 23 and lubricant headers 24 at each side of the rolling mill. The strip material 1 is fed and taken up between the tension reels 19 to be rolled repeatedly. Terms "IN" and "OUT" in the description below respectively represent the entrance side of the rolling mill 17 to which the strip material 1 is supplied and the exit side of the rolling mill 17 from which the strip material 1 is ejected.

[0068] Initially, the strip material 1 is placed on the pay-off reel 18, taken out and guided by pinch rolls 20, and transferred into the rolling mill 17. In the rolling mill 17, the coolant headers 23 and the lubricant headers 24 apply fluid to the working rolls 2 and the areas (roll bytes) where the working rolls 2 touch the strip material 1 to cool and lubricate them during rolling. The rolled strip is taken up by the OUT tension reel 19. The roll cooling fluid and the lubricating fluid are usually the same fluid and hereinafter they will be called simply as coolant. (oil). Said coolant oil is not fed from the OUT spray headers 23 and 24. This is because any remaining oil on the strip surface may increase the possibility of coil slippage, skewing and uncoiling of the reel 19. A fluid cutting means 22 are provided to remove the coolant oil almost completely However, complete removal of the fluid is very difficult and the possibility of coil slippage, skewing and uncoiling of the reel 19 will be greater if the rolled material has an edge-up due to thermalcrown (as explained already). Further, this possibility increases more in the cold reversible rolling facility that moves the strip forward and backward by the IN and OUT tension rolls to roll repeatedly. Usually, when a great edge-up shape is found by the OUT shape detector 21, the rolling is carried out carefully (e.g., by slowing down the rolling rate).

[0069] From the above description, we find that thermal crown controlling by a cold reversible rolling mill in accordance with the present invention will have a striking effect to increase rolled surface qualities, yields, and productivity of rolling.

[0070] FIG.20 is a schematic illustration of an aluminum rolling system to which an embodiment of the present invention is applied. Unlike the general reversible rolling system for steel strips, this aluminum rolling system employing a one-way rolling method has a tension reel 19 only in the OUT side and a pay-off reel 18 in the IN side. Usually the one-way rolling method repeatedly rolls dozens of coils as one unit. In other words, each coil is placed on the pay-off reel 18, fed into the rolling mill, and taken out by the tension reel 19. Dozens of coils in a unit are rolled through in sequence for one path at a time and then rolled repeatedly for the next and later paths until the target strip thickness is obtained. As explained above, this rolling method does not transfer any coil from the tension roll to the pay-off reel and requires no shape detector 21 in the IN side and no coolant header 23 and 24 in the OUT side.

[0071] In the one-way rolling as in the aluminum rolling mill, the leading and trailing ends of each coil are always rolled without being tensioned in each rolling path. Without a tension, the coil is apt to have meanders in the leading and trailing parts of the coil. This tendency becomes greater as the coil is rolled thinner (towards the target thinness). To suppress such meanders, it is preferable to remove any factor such as a thermal crown that causes a disturbance. In this sense, it is very significant to apply, to aluminum rolling, the rolling mills in accordance with the present invention which has a high ability to control thermal crowns.

[0072] As already explained, the aluminum rolling system using coolant oil of a low flashing point is likely to cause a fire at a break of the coil. One of the main coil break causes is an edge-up phenomenon due to a thermal crown as already explained. Particularly, soft materials such as aluminum are affected by thermal crowns and likely to be broken in rolling. Usually, such a rolling system 17 is placed in a large fire-extinguishing system (not visible in FIG.18) for quick fire extinguishing. However, once a fire breaks, many parts such as oil seals, flexible hoses, and wires may be seriously damaged even when it is extinguished immediately. It will require huge repairing money and time. Therefore, it is very significant to control thermal crowns effectively in aluminum rolling systems, to reduce the possibility of fire, and consequently to improve the operability and productivity of rolling.

[0073] The present invention enables stable production of high-quality cold rolling products, controlling the ever-changing thermal crowns during rolling without causing any flaws in the rolled surfaces and with quick responses to ever-changing thermal crowns.

Claims

1. A cold rolling mill of at least four-high or more-than-4-high comprising first shifting equipment (12, 13) which can shift a pair of upper and lower working rolls (2) in opposite directions and roll bending equipment (10, 11) which controls the bending of said pair of working rolls, wherein said cold rolling mill further comprises

   locally gradually-thickened-toward-end parts (2a) provided on said working rolls (2) at one ends thereof so as to be symmetrical with respect to a point,

   a first shape control means (10b) for controlling a thermal crown formed on each of said pair of working rolls together with said locally gradually-thickened-toward-end parts, and

   a second shape control means (11a) for controlling to form a concave crown in the center of said rolled material (1).

2. Rolling mill according to claim 1, **characterized in that** said roll bending equipment comprises decremental bending equipment (10b) and said first shape control means is said decrement bending equipment.

3. Rolling mill according to claim 1 or 2, **characterized in that** said rolling mill is a 6-high mill comprising a pair of upper and lower intermediate rolls (3) and a second shifting equipment which can rotate said pair of upper and lower intermediate rolls in opposite directions, said first shape control means is said second shifting equipment.

4. Cold rolling mill of at least four-high or more-than 4-high comprising first shifting equipment (12, 13) which can shift a pair of upper and lower working rolls (2) in opposite directions and roll bending equipment (10, 11) which controls the bending of said pair of working rolls, wherein

   each of said upper and lower working rolls (2) has a locally gradually-thickened-toward-end part (2a) in which the diameter increases toward one end of the working roll,

   said locally gradually-thickened-toward-end parts are disposed vertically symmetrically with respect to a point,

   said roll bending equipment as the first shape control means comprises decremental bending equipment (10b) which works to narrow the gap between said pair of upper and lower working rolls (2), and

   said rolling mill further comprises a second shape control means (11a) for controlling to form a concave crown in the center of said rolled material.

5. A cold rolling mill of at least 4-high or more-high for a cold reversible rolling facility comprising first shifting equipment (12, 13) which can shift a pair of upper and lower working rolls (2) in opposite directions and roll bending equipment (10, 11) which controls the bending of said pair of working rolls (2), wherein

   each of said upper and lower working rolls (2) has a locally gradually-thickened-toward-end part (2a) which increases its diameter on one end of the working roll,

   said locally gradually-thickened-toward-end parts (2a) are disposed vertically symmetrically with respect to a point,

   said roll bending equipment as the first shape control means (10b) comprises decremental bending equipment which works to narrow the gap between said pair of upper and lower working rolls (2), and

   said rolling mill further comprises a second shape control means (11a) for controlling to form a concave crown in the center of said rolled material (1).

6. A cold rolling mill of at least four-high or more-high for a cold aluminum rolling facility comprising first shifting equipment (12, 13) which can shift a pair of upper and lower working rolls (2) in opposite directions and roll bending equipment (10, 11) which controls the bending of said pair of working rolls, wherein

   each of said upper and lower working rolls (2) has a locally gradually-thickened-toward-end part (2a) in which the diameter increases on one end of the working roll,

said locally gradually-thickened-toward-end parts (2a) are disposed vertically symmetrically with respect to a point,

said roll bending equipment as the first shape control means (10b) comprises decremental bending equipment which works to narrow the gap between said pair of upper and lower working rolls (2), and

said rolling mill further comprises a second shape control means (11a) for controlling to form a concave crown in the center of said rolled material (1).

7. Rolling mill according to any of claims 1 and 4 to 6, **characterized in that** said rolling mill is a 6-high mill comprising a pair of upper and lower intermediate rolls (3) which can move axially and said second shape control means is equipped with an incremental bending equipment (11a) which controls the bending of said pair of intermediate rolls (3).

8. Rolling mill according to claim 7, **characterized in that** each of said intermediate rolls (3) have a locally tapered part (3a) on the side where the gradually-thickened-toward-end part (2a) exists so that the tapered part may be engaged with said gradually-thickened-toward-end part of each working roll (2) and the rate of diameter changing of said tapered part is equal to or greater than the rate of diameter changing of the gradually-thickened-toward-end part.

9. Rolling mill according to any of claims 1 and 4 to 8, **characterized in that** said rolling mill is a 6-high mill comprising a pair of upper and lower intermediate rolls (3) each of which has a curved roll crown containing both a maximum and a minimum all over the roll and said second shape control means (11a) has shifting equipment which shifts said pair of upper and lower intermediate rolls (3) in opposite directions.

10. Rolling mill according to any of claims 1 and 4 to 6, **characterized in that** said rolling mill is a 6-high mill comprising a pair of upper and lower intermediate rolls (3) which can move axially and said second shape control means has a roll-crossing mechanism which tilts at least said pair of intermediate rolls (3) horizontally with the center of the mill approximately as the center of rotation.

11. Rolling mill according to any of claims 1 and 4 to 6, **characterized in that** said rolling mill is a 4-high rolling mill and said second shape control means (11a) is equipped with a roll-crossing mechanism which tilts said pair of working rolls (2) or one pair of rolls supporting said working rolls with the center of the mill approximately as the center of rotation.

12. Rolling mill according to any of claims 1 and 4 to 6, **characterized in that**

said rolling mill is a 4-high mill,

each of the pair of supporting rolls (4) for supporting said working rolls has a roll crown which is tapered from about the center of the roll towards one end of the roll,

said roll crowns are disposed vertically symmetrically with respect to a point, and

said second shape control means (11a) is equipped with the shifting equipment which can move said supporting rolls (4) in different directions.

13. Rolling mill according to any of claims 1 and 4 to 6, **characterized in that** the diameter of each of said upper and lower working rolls (2) is expressed by

$$1/6Wm + 50 \leq Dw \leq 1/6Wm + 250$$

wherein
Dw is the diameter of each of the working rolls and Wm is the maximum width of a sheet (1) to be rolled.

14. A cold rolling mill comprising:

a pair of work rolls (2) each provided with a roll-contour shape having a portion thickened-toward-end (2a) which increases in diameter toward a roll end in the vicinity of the roll end on one end side of a roll barrel portion thereof, said work rolls being arranged so that said thickened-toward-end portions are positioned at places on the opposite sides of the barrel portions in the roll axis direction;

intermediate rolls (3) supporting said work rolls (2), respectively;

roll bending device (10) for applying roll bending force on said work rolls (2); and

an intermediate roll bending device (11) for applying roll bending force on said intermediate rolls (3).

15. A cold rolling mill comprising:

a pair of working rolls (2) each, provided with a roll-contour shape having a portion (2a) thickened-toward-end which increases in diameter toward a roll end in the vicinity of the roll end on one end side of a roll barrel portion thereof, and rolling rolling materials, said working rolls being arranged so that said thickened-toward-end portions (2a) are positioned at places on the opposite sides of the barrel portions in the roll axis direction;

intermediate rolls (3) supporting said working rolls (2), respectively;

backup rolls (4) supporting said intermediate rolls (3), respectively;

a roll bending device (10) for applying roll bending force on said working rolls; and

an intermediate roll crossing mechanism for crossing the roll axes of said intermediate rolls in a horizontal plane against a perpendicular direction to the rolling material travelling direction, or a roll shifting device for shifting said intermediate rolls along the roll axis direction.

16. A cold rolling mill comprising:

a pair of working rolls (2) each provided with a roll-contour shape having a portion thickened-toward-end (2a) which increases in diameter toward a roll end in the vicinity of the roll end on one end side of a roll barrel portion thereof, said working rolls being arranged so that said thickened-toward-end portions (2a) are positioned at places on the opposite sides of the barrel portions in the roll axis direction;

supporting rolls (4) supporting said working rolls, respectively;

a roll bending device (10) for applying roll bending force on said working rolls; and

a supporting roll shifting device for shifting said supporting rolls along the roll axis direction.

17. A cold rolling mill comprising:

a pair of working rolls (2) each , provided with a roll-contour shape having a portion thickened-toward-end (2a) which increases in diameter toward a roll end in the vicinity of the roll end on one end side of a roll barrel portion thereof, and rolling rolling materials, said working rolls being arranged so that said thickened-toward-end portions (2a) are positioned at places on the opposite sides of the barrel portions in the roll axis direction;

supporting rolls (4) supporting said working rolls, respectively;

a roll bending device (10) for applying roll bending force on said working rolls (2); and

a roll crossing mechanism for crossing the roll axes of said working rolls in a horizontal plane against a perpendicular direction to the rolling material travelling direction.

18. A rolling method which comprises the steps of:

using shape detectors which measure the shapes of a sheet at least after being rolled and a 4-high or more-high cold rolling mill which comprises

shifting equipment which can shift one pair of upper and lower working rolls each of which has a locally gradually-thickened-toward-end part on one end of respective working rolls with the locally gradually-thickened-toward-end parts disposed vertically symmetrically with respect to a point,

roll bending equipment which controls bending of said pair of working rolls and has, as a first shape control means, decremental bending equipment which works to narrow the gap between said pair of working rolls, and

a second shape control means for forming a concave crown in the center of said rolled material,

adjusting the position of said one pair of upper and lower working rolls by said shifting equipment so that side edges of the rolled sheet may be limited by said gradually-thickened-toward-end parts of said working rolls before starting rolling,

approximately fixing the shift position of said pair of upper and lower working rolls while rolling is in progress, and

determining the operations of said first and second shape control means so that their effects on the sheet may work reversely according to the output of said shape detectors.

19. A rolling method in accordance with Claim 18, wherein the operation of said first shape control means is determined according to the output of said shape detector placed near the edge of the sheet and the operation of said second shape control means is determined according to the output of said shape detector placed near the center of the sheet.

20. A rolling method which comprises the steps of:

using shape detectors which measure the shapes of a sheet at least after being rolled and a 6-high cold rolling mill which comprises

first shifting equipment which can shift one pair of upper and lower working rolls each of which has a locally gradually-thickened-toward-end part on one end of respective working rolls with the locally gradually-thickened-toward-end parts disposed vertically symmetrically with respect to a point,

second shifting equipment which can rotate one pair of upper and lower intermediate rolls which support said working rolls reversely, and

a second shape control means for forming a concave crown in the center of said rolled material,

adjusting the position of said one pair of upper and lower working rolls by said first shifting equipment so that side edges of the rolled sheet may be limited by said gradually-thickened-toward-end parts of said working rolls before starting rolling,

approximately fixing the shift position of said pair of upper and lower working rolls while rolling is in progress, and

determining the operations of said second shifting equipment and said shape control means according to the output of said shape detectors.

21. A rolling method in accordance with Claim 20, wherein the operation of said second shifting equipment is determined according to the output of said shape detector placed near the edge of the sheet and the operation of said shape control means is determined according to the output of said shape detector placed near the center of the sheet.

22. A rolling method of a cold rolling mill comprising a pair of working rolls each, provided with a roll-contour shape having a portion thickened-toward-end which increases in diameter toward a roll end in the vicinity of the roll end on one end side of a roll barrel portion thereof, said working rolls being arranged so that said thickened-toward-end portions are positioned at places on the opposite sides of the barrel portions in the roll axis direction, intermediate rolls supporting said working rolls, respectively, and backup rolls supporting said intermediate rolls, respectively, wherein said method comprises the steps of

controlling thermal crown during rolling by applying roll bending force on said working rolls, and controlling body crow at a central portion of the plate depth by applying roll bending force on said intermediate rolls.

23. A rolling method of a cold rolling mill comprising a pair of working rolls each, provided with a roll-contour shape having a portion thickened-toward-end which increases in diameter toward a roll end in the vicinity of the roll end on one end side of a roll barrel portion thereof, said working rolls being arranged so that said thickened-toward-end portions are positioned at places on the opposite sides of the barrel portions in the roll axis direction, intermediate rolls supporting said working rolls, respectively, and backup rolls supporting said intermediate rolls, respectively, wherein said method comprises the steps of

controlling thermal crown during rolling by applying roll bending force on said working rolls,

controlling body crown at a central portion of the plate width by crossing the roll axes of said intermediate rolls in a horizontal plane against a perpendicular direction to the rolling material travelling direction, or shifting said intermediate rolls along the roll axis direction.

24. A rolling method of a cold rolling mill comprising a pair of working rolls each, provided with a roll-contour shape having a portion thickened-toward-end which increases in diameter toward a roll end in the vicinity of the roll end on one end side of a roll barrel portion thereof, said working rolls being arranged so that said thickened-toward-end portions are positioned at places on the opposite sides of the barrel portions in the roll axis direction, and support rolls supporting said working rolls, respectively, wherein said method comprises the steps of

controlling thermal crown during rolling by applying roll bending force on said working rolls, and

controlling body crow at a central portion of the plate depth by shifting said support rolls along a roll axis direction.

25. A rolling method of a cold rolling mill comprising a pair of working rolls each, provided with a roll-contour shape having a portion thickened-toward-end which increases in diameter toward a roll end in the vicinity of the roll end on one end side of a roll barrel portion thereof, and rolling rolling materials, said working rolls being arranged so that said thickened-toward-end portions are positioned at places on the opposite sides of the barrel portions in the roll axis direction, and support rolls supporting said working rolls, respectively,
wherein said method comprises the steps of

controlling thermal crown during rolling by applying roll bending force on said working rolls, and

controlling body crow at a central portion of the plate depth by crossing the roll axes of said work rolls in a horizontal plane against a perpendicular direction to the rolling material travelling direction.

FIG. 1

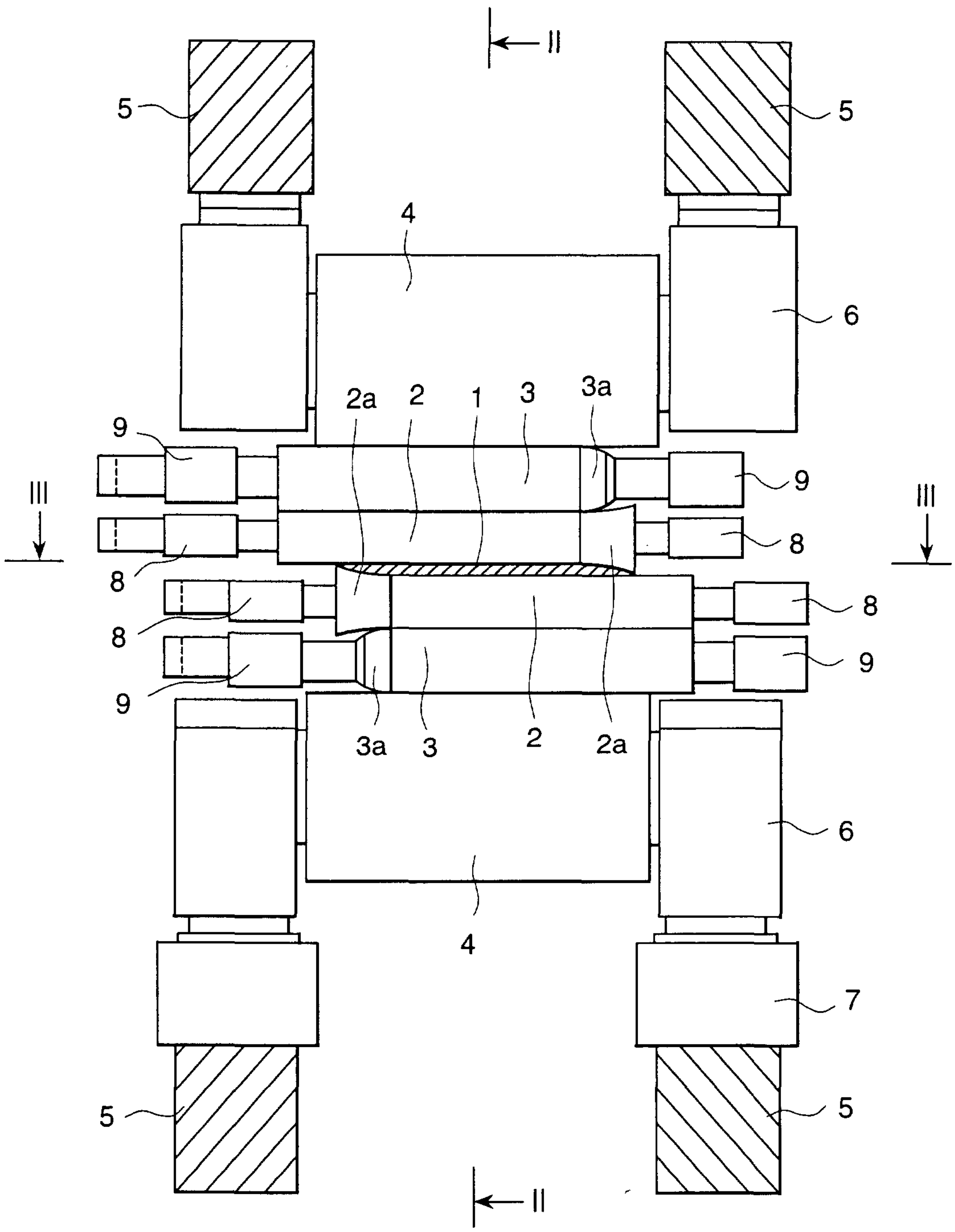


FIG. 2

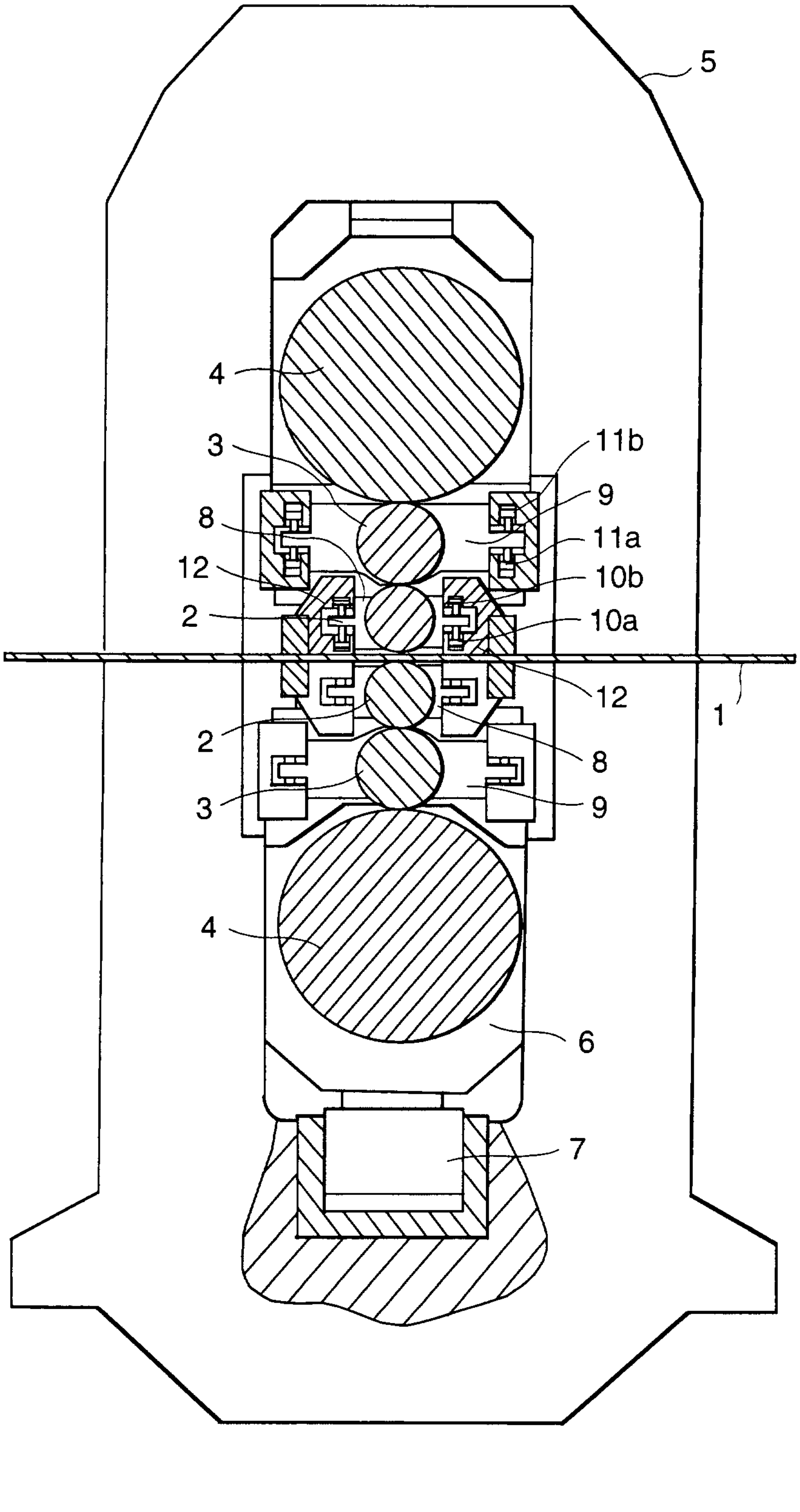


FIG. 3

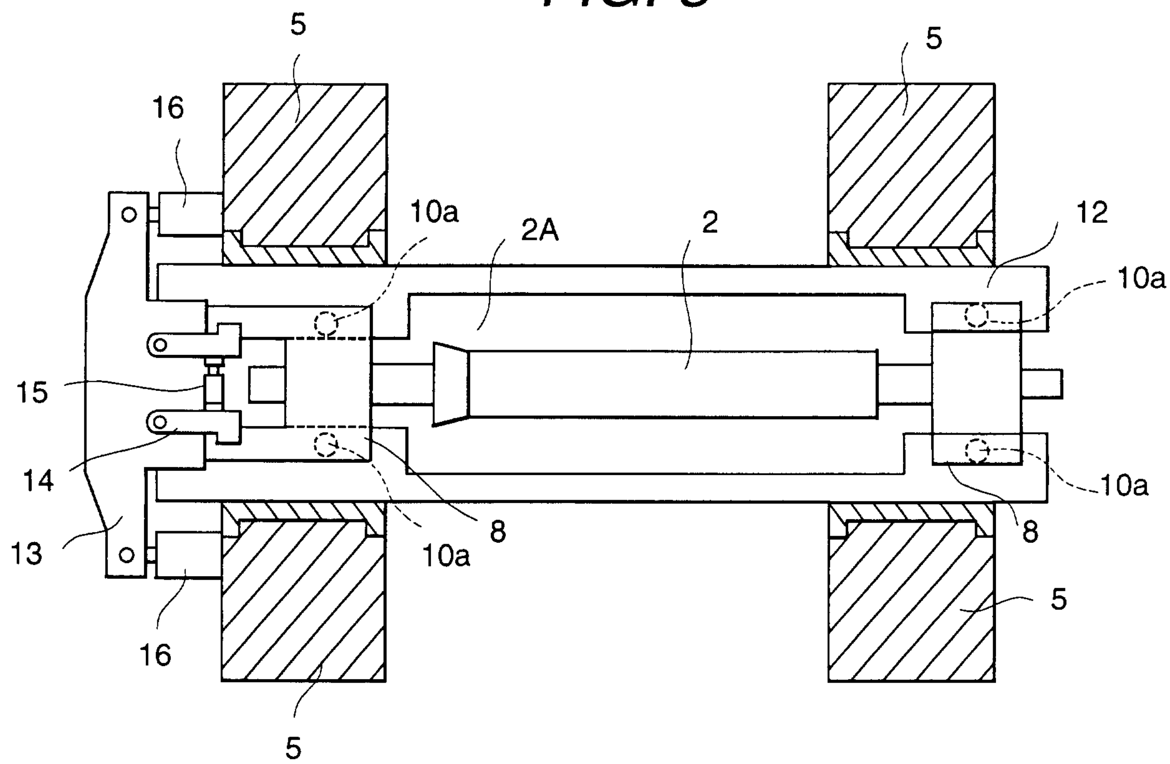

5
5
16
10a
2A
2
12
10a
15
14
13
8
10a
8
10a
5
16
5

FIG. 4

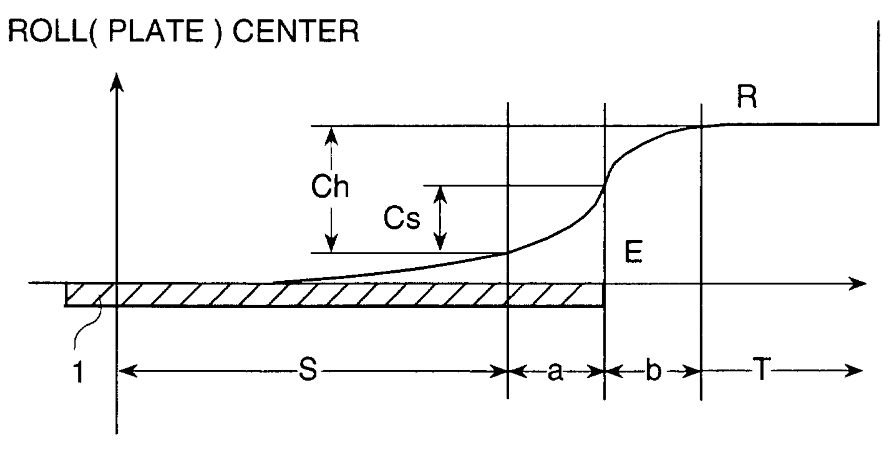

ROLL(PLATE) CENTER
R
Ch
Cs
E
1
S
a
b
T

FIG. 5

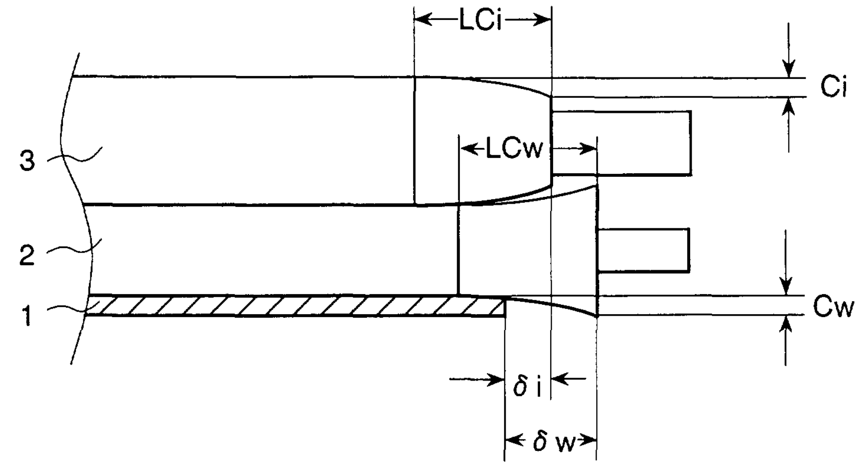

LCi
Ci
3
LCw
2
1
Cw
δ i
δ w

FIG. 6

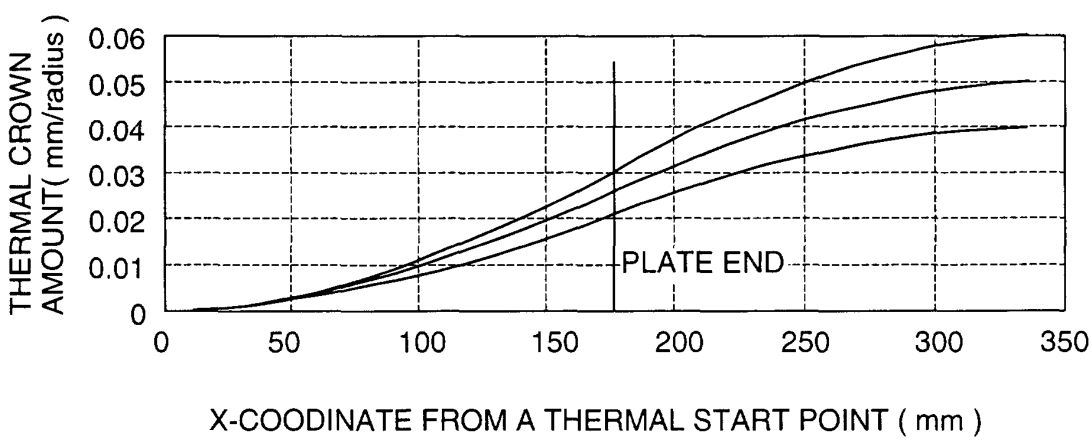

THERMAL CROWN AMOUNT(mm/radius)
0.06
0.05
0.04
0.03
0.02
0.01
0
0
50
100
150
200
250
300
350
PLATE END
X-COODINATE FROM A THERMAL START POINT (mm)

FIG. 7

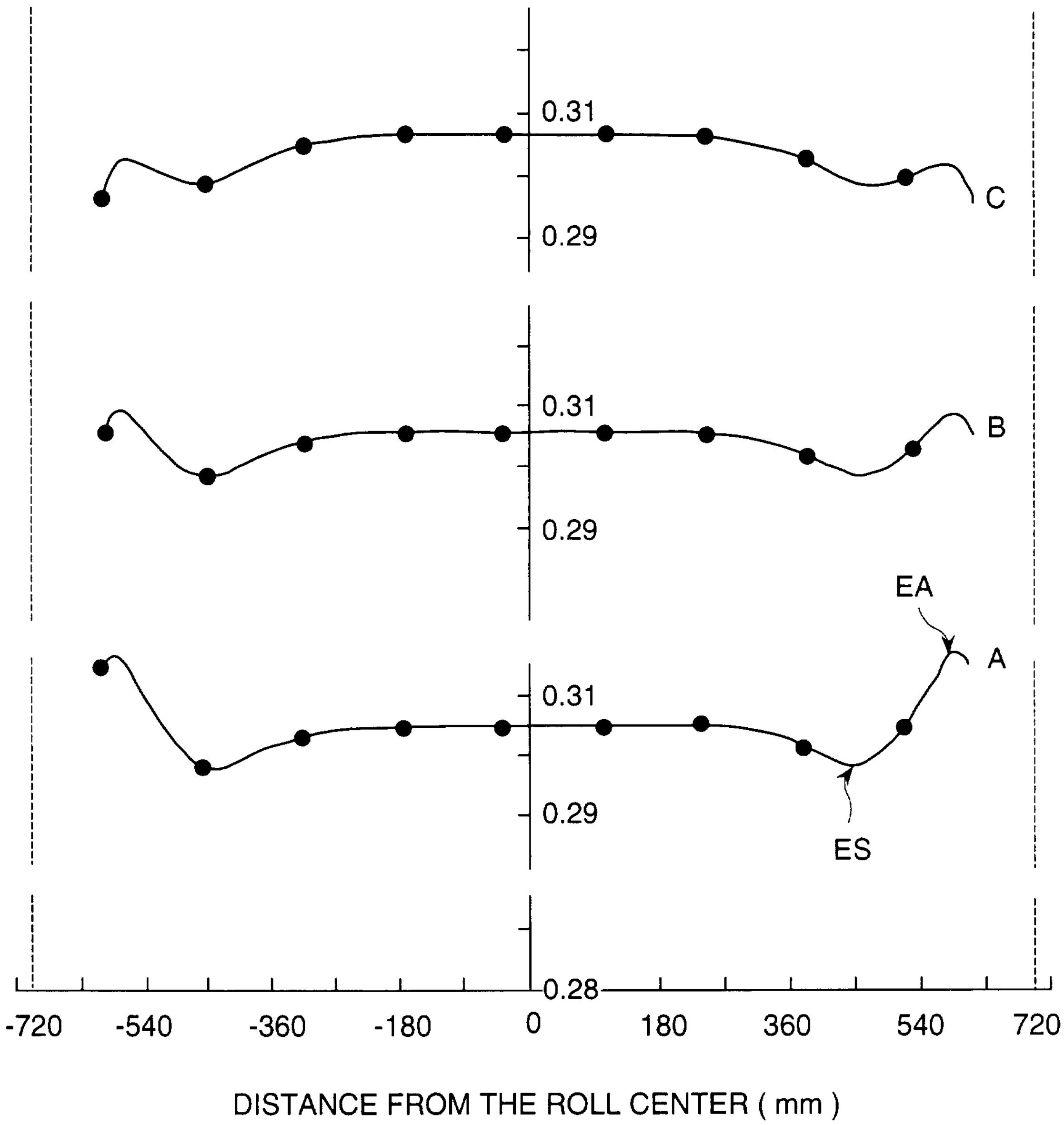

0.31
0.29
C
0.31
0.29
B
EA
A
0.31
0.29
ES
0.28
-720
-540
-360
-180
0
180
360
540
720
DISTANCE FROM THE ROLL CENTER (mm)

FIG. 8

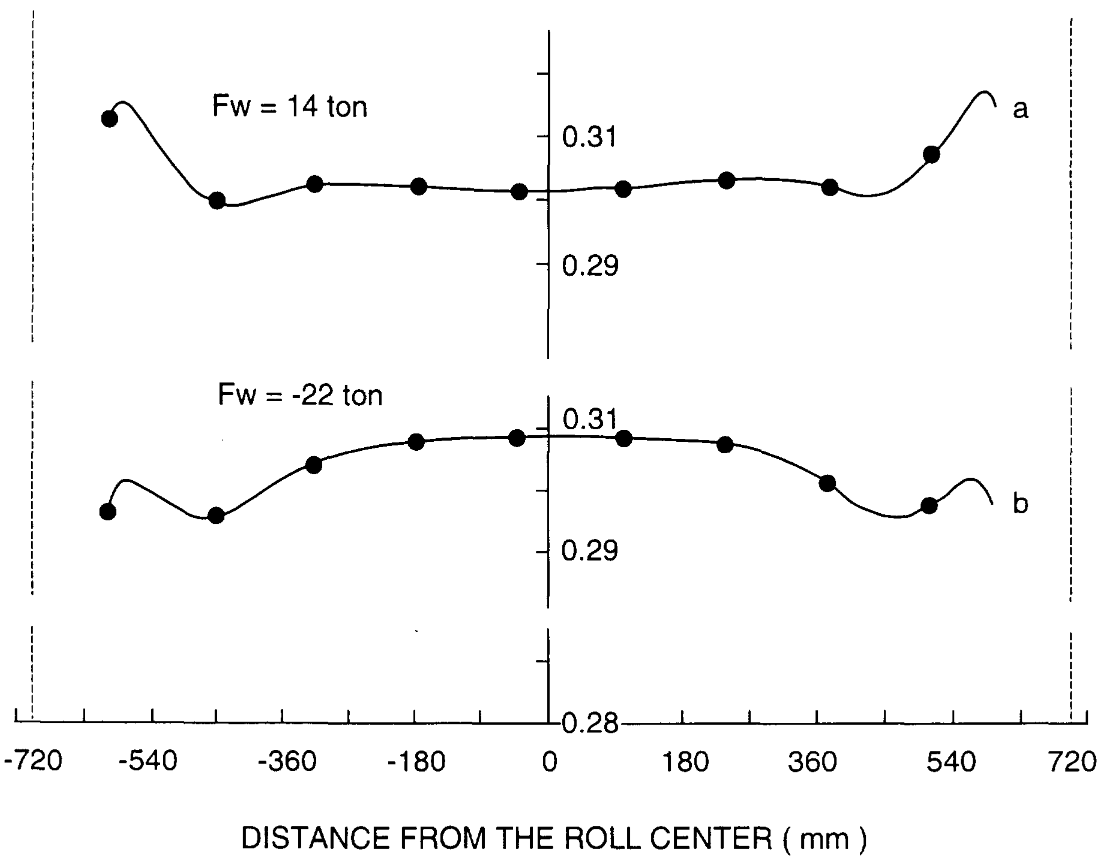

Fw = 14 ton
0.31
0.29
a
Fw = -22 ton
0.31
0.29
b
0.28
-720
-540
-360
-180
0
180
360
540
720
DISTANCE FROM THE ROLL CENTER (mm)

FIG. 9

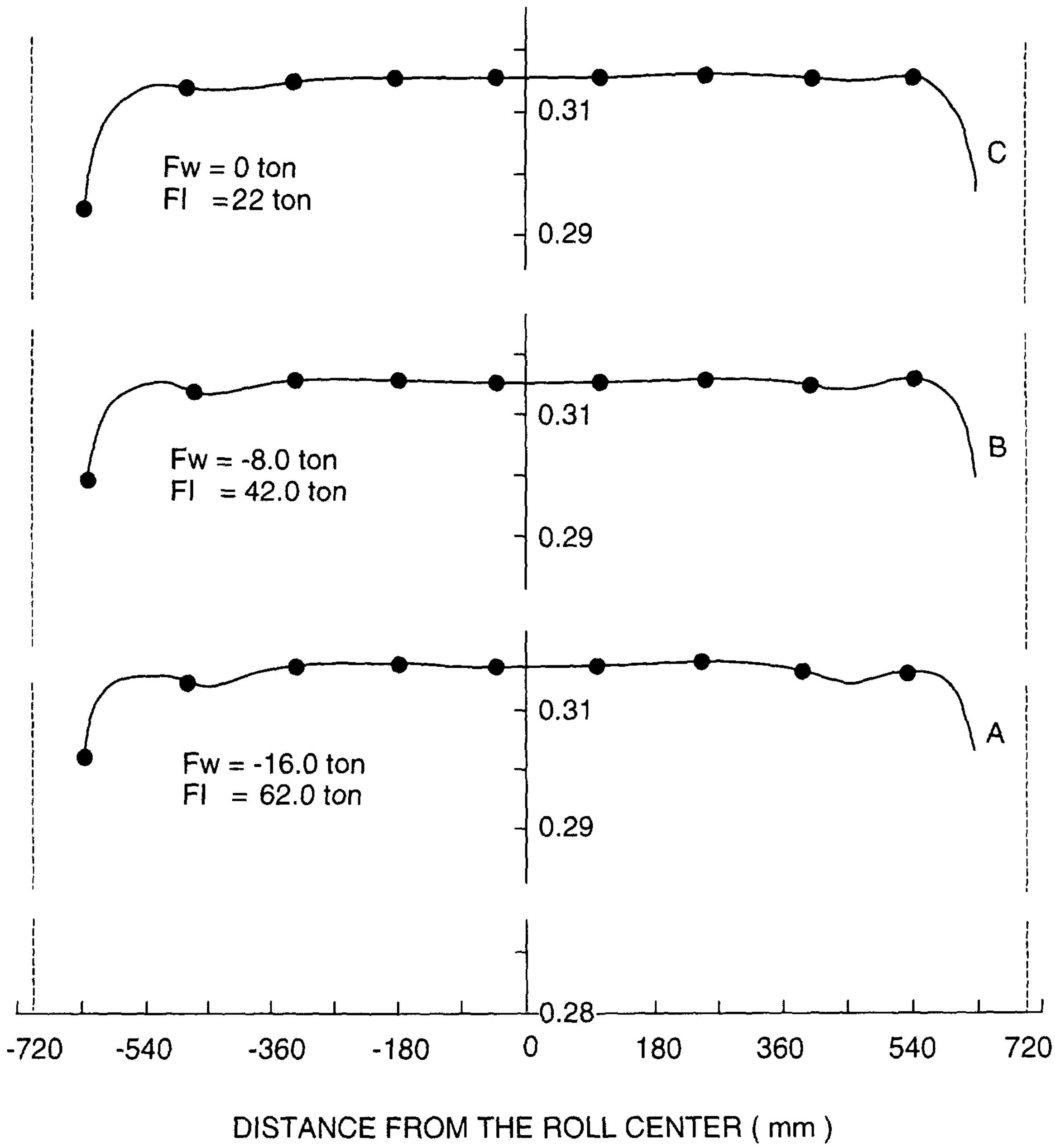

0.31
0.29
Fw = 0 ton
Fl =22 ton
C
0.31
0.29
Fw = -8.0 ton
Fl = 42.0 ton
B
0.31
0.29
Fw = -16.0 ton
Fl = 62.0 ton
A
0.28
-720
-540
-360
-180
0
180
360
540
720
DISTANCE FROM THE ROLL CENTER (mm)

FIG. 10

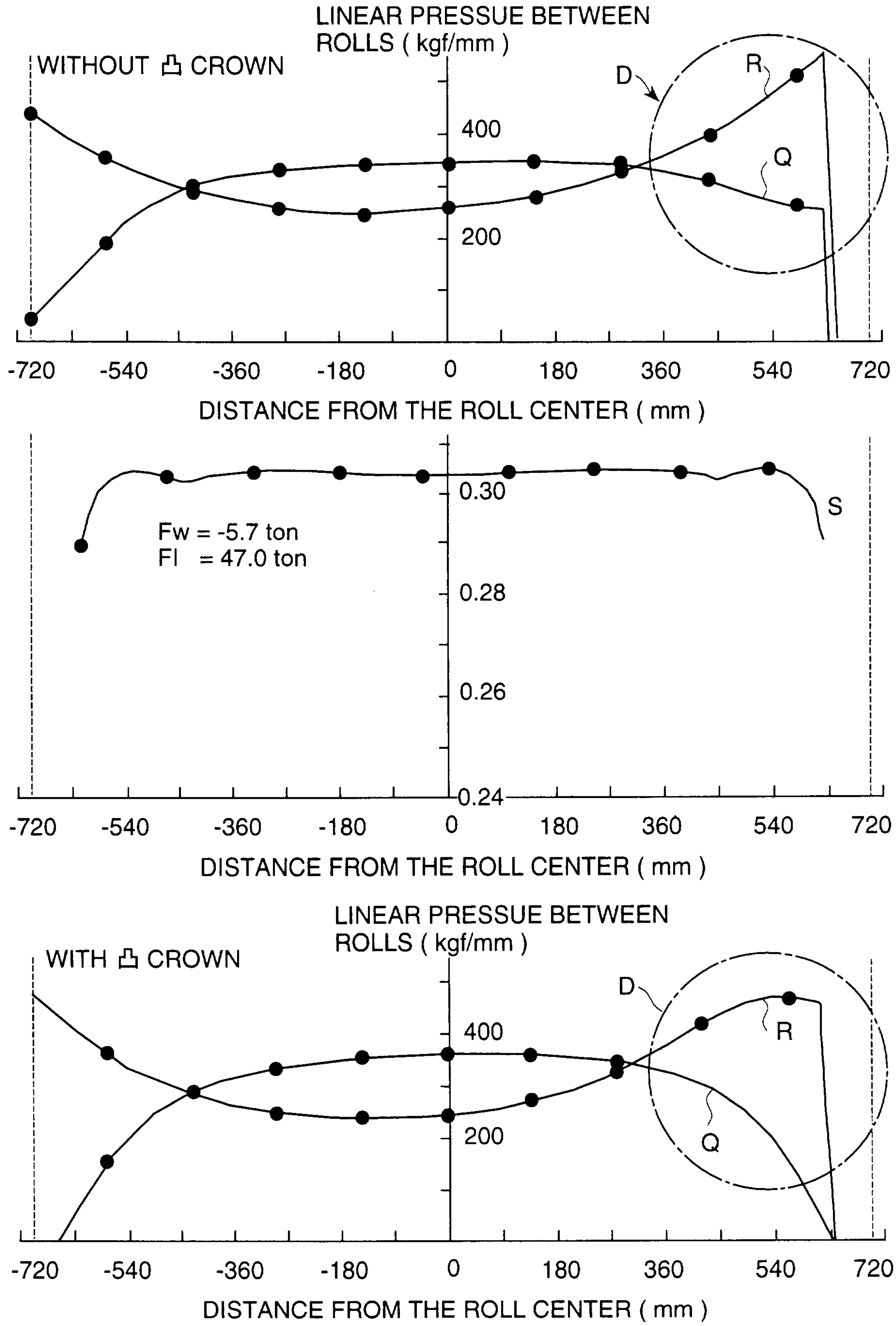

LINEAR PRESSUE BETWEEN
ROLLS (kgf/mm)
WITHOUT 凸 CROWN
D
R
Q
400
200
-720
-540
-360
-180
0
180
360
540
720
DISTANCE FROM THE ROLL CENTER (mm)
0.30
0.28
0.26
0.24
S
Fw = -5.7 ton
Fl = 47.0 ton
-720
-540
-360
-180
0
180
360
540
720
DISTANCE FROM THE ROLL CENTER (mm)
LINEAR PRESSUE BETWEEN
ROLLS (kgf/mm)
WITH 凸 CROWN
D
R
Q
400
200
-720
-540
-360
-180
0
180
360
540
720
DISTANCE FROM THE ROLL CENTER (mm)

FIG. 11

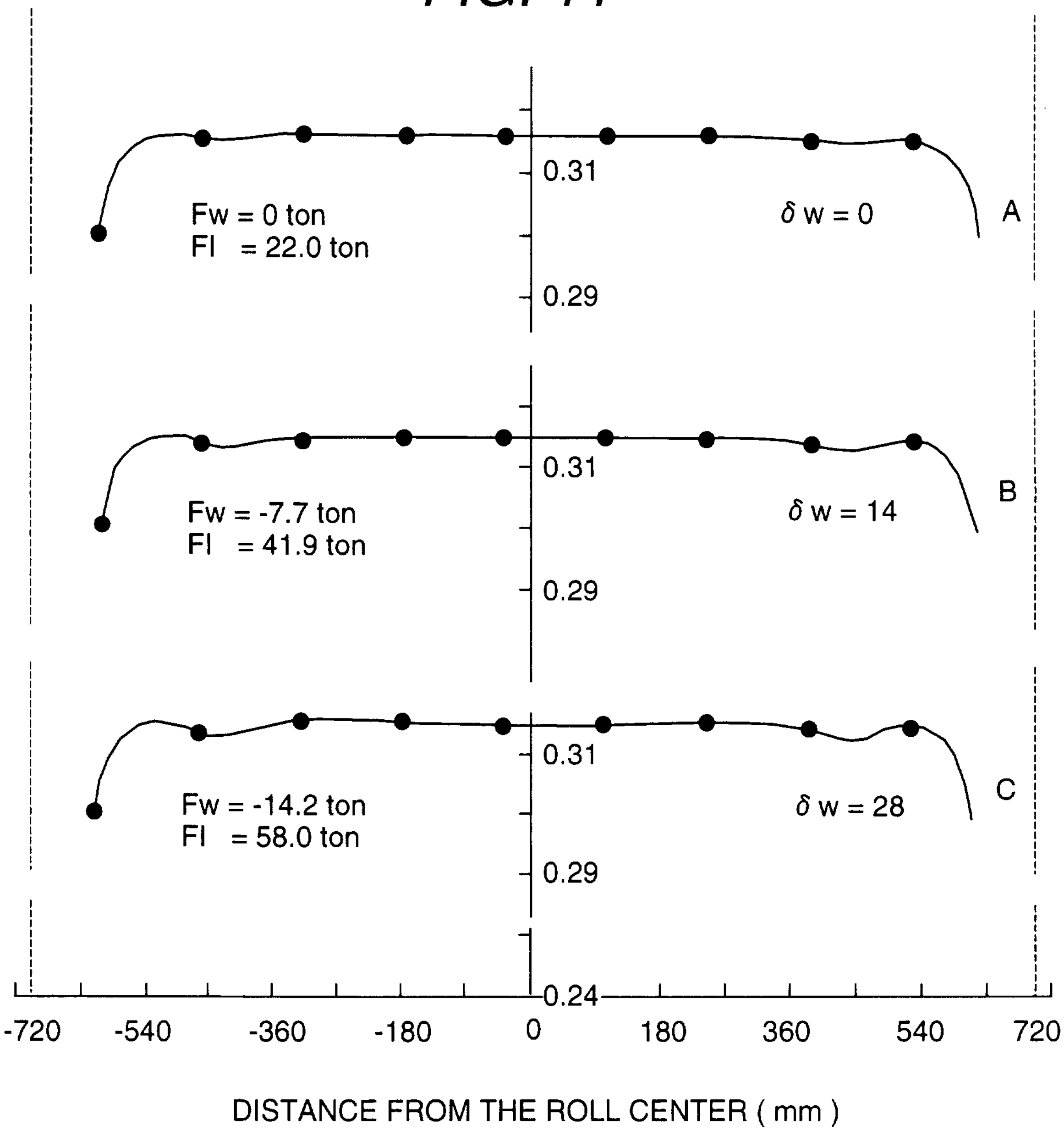

0.31
0.29
Fw = 0 ton
Fl = 22.0 ton
δ w = 0
A
0.31
0.29
Fw = -7.7 ton
Fl = 41.9 ton
δ w = 14
B
0.31
0.29
Fw = -14.2 ton
Fl = 58.0 ton
δ w = 28
C
0.24
-720
-540
-360
-180
0
180
360
540
720
DISTANCE FROM THE ROLL CENTER (mm)

FIG. 12

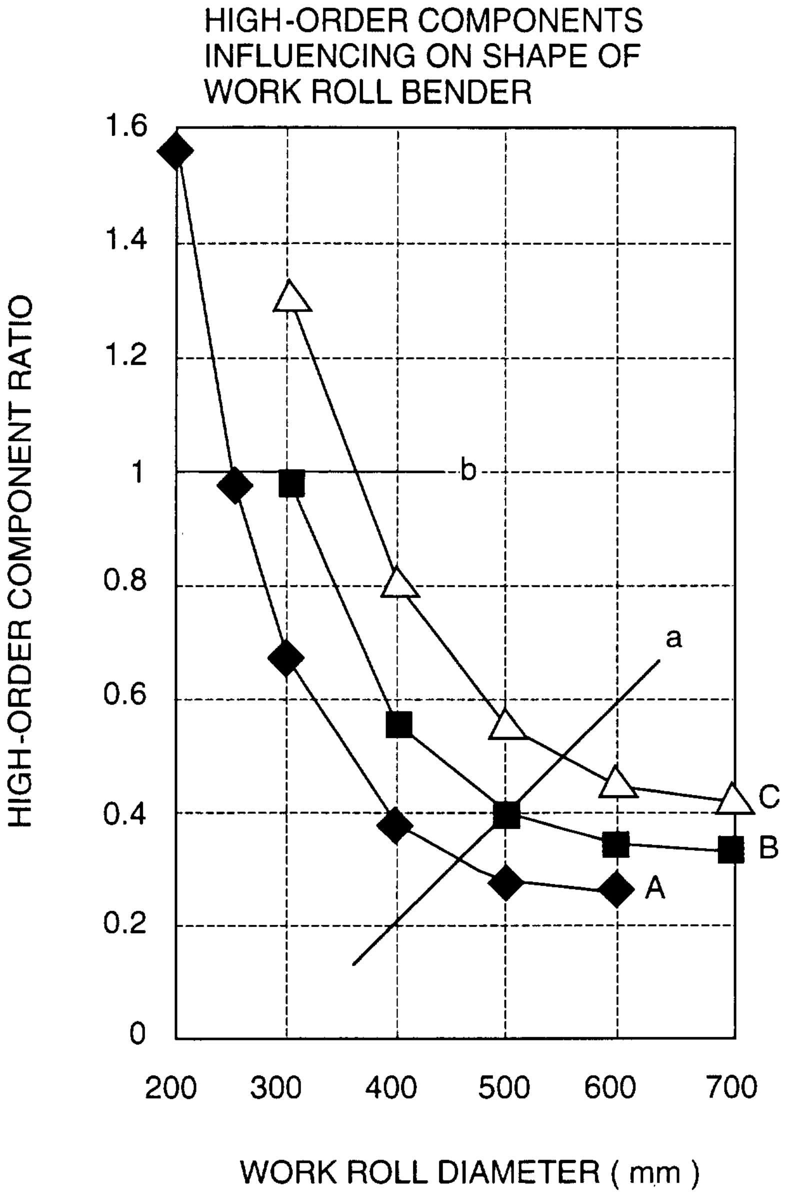

HIGH-ORDER COMPONENTS
INFLUENCING ON SHAPE OF
WORK ROLL BENDER
HIGH-ORDER COMPONENT RATIO
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
b
a
A
B
C
200
300
400
500
600
700
WORK ROLL DIAMETER (mm)

FIG. 13

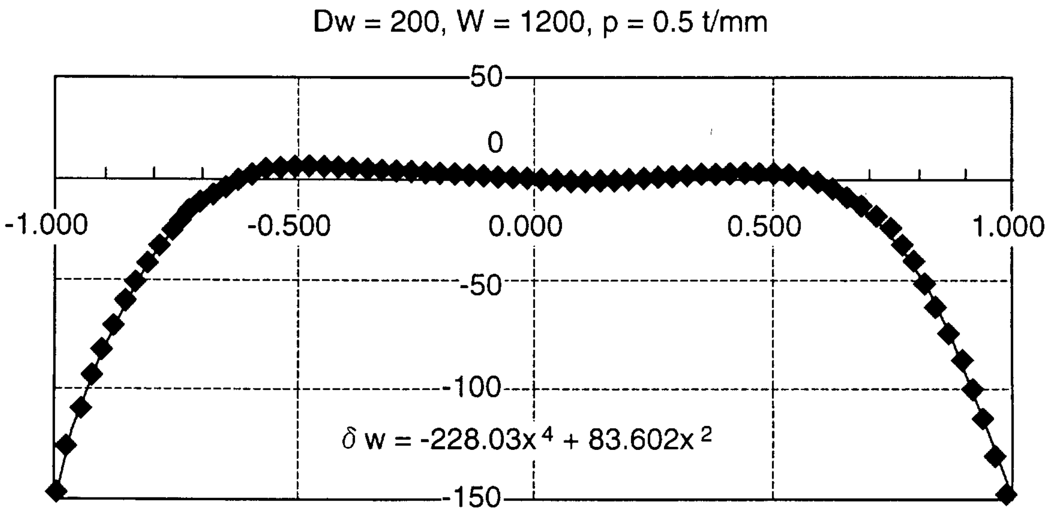

Dw = 200, W = 1200, p = 0.5 t/mm
50
0
-50
-100
-150
-1.000
-0.500
0.000
0.500
1.000
δ w = -228.03x 4 + 83.602x 2

FIG. 14

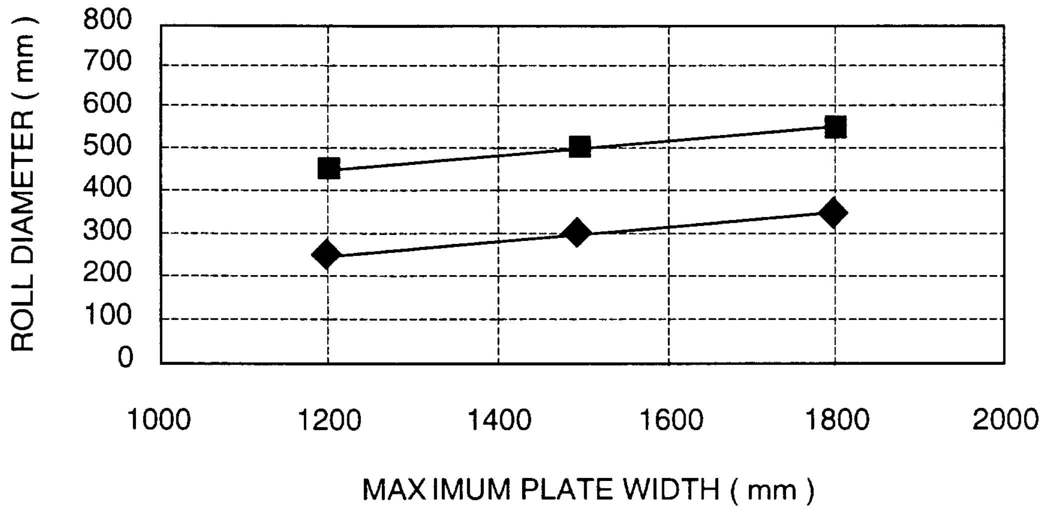

ROLL DIAMETER (mm)
800
700
600
500
400
300
200
100
0
1000
1200
1400
1600
1800
2000
MAXIMUM PLATE WIDTH (mm)

FIG. 15

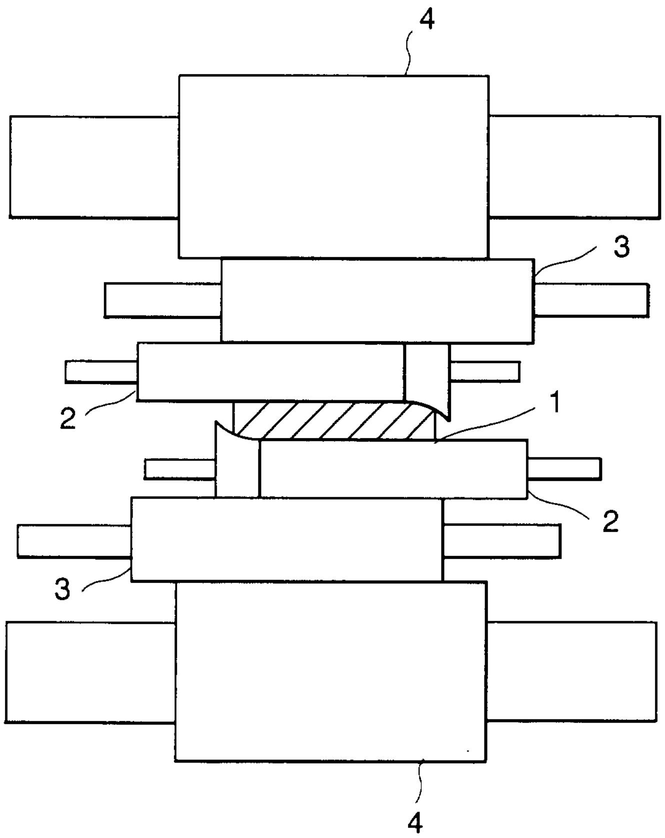


FIG. 16

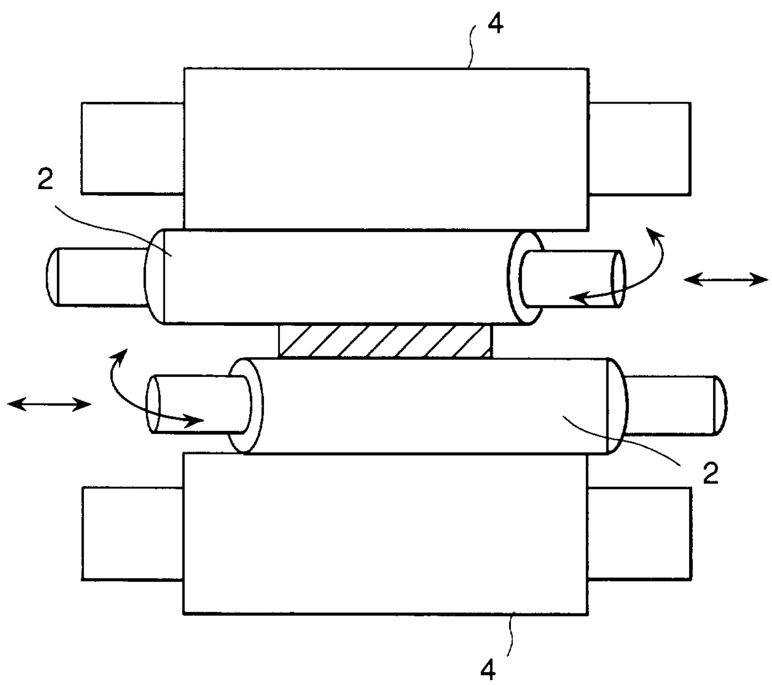


FIG. 17

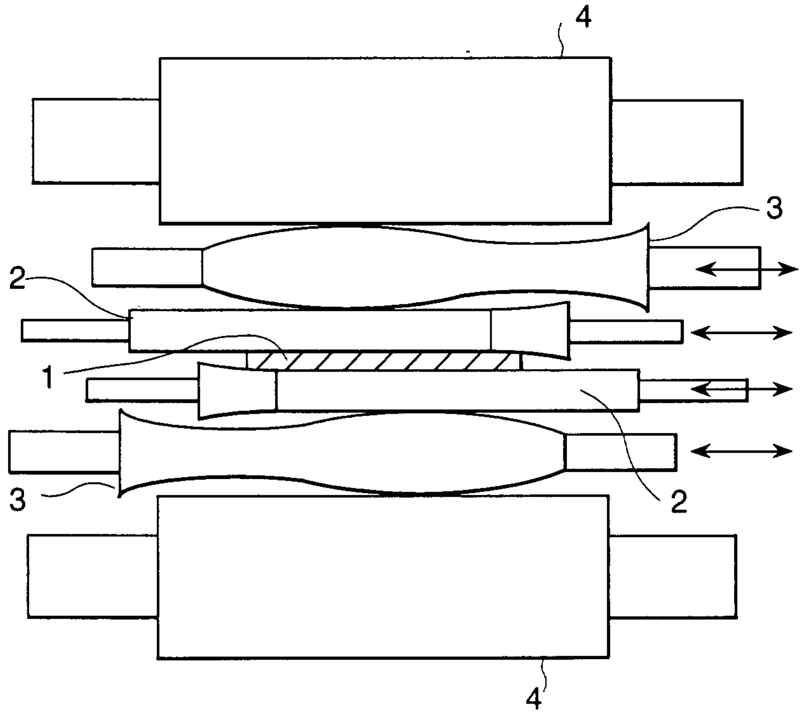


FIG. 18

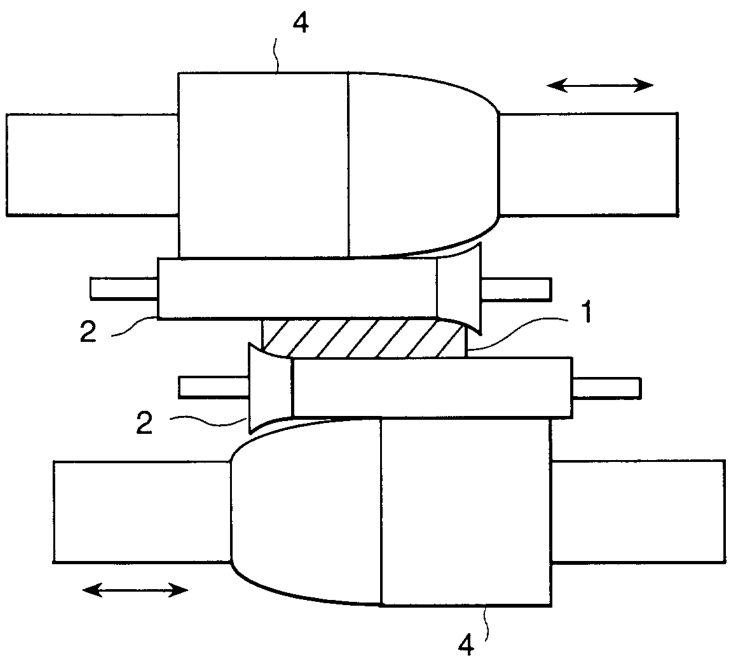


FIG. 19

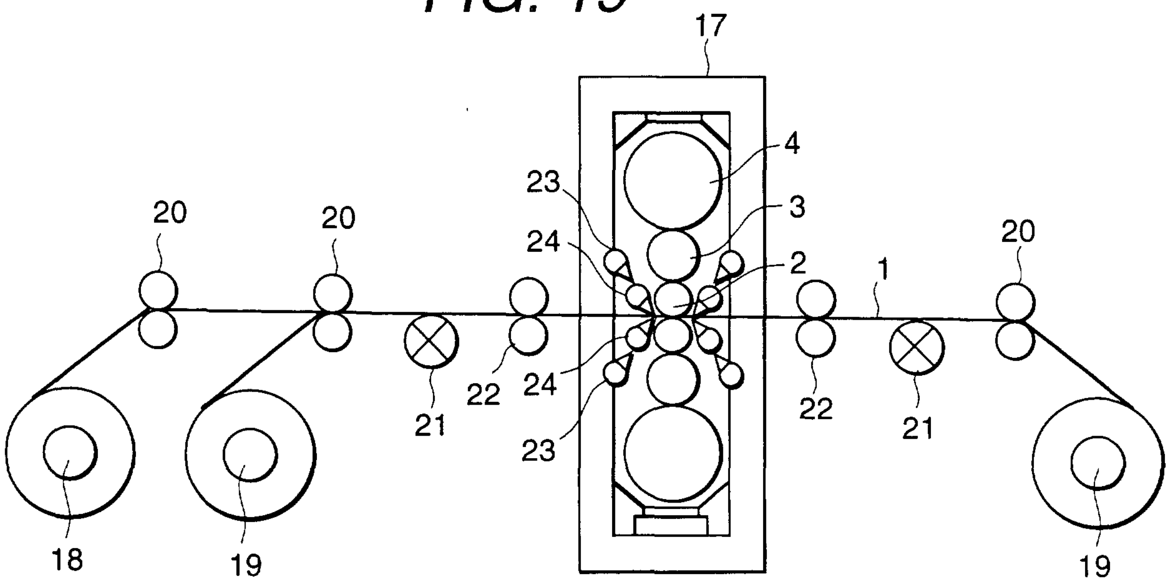
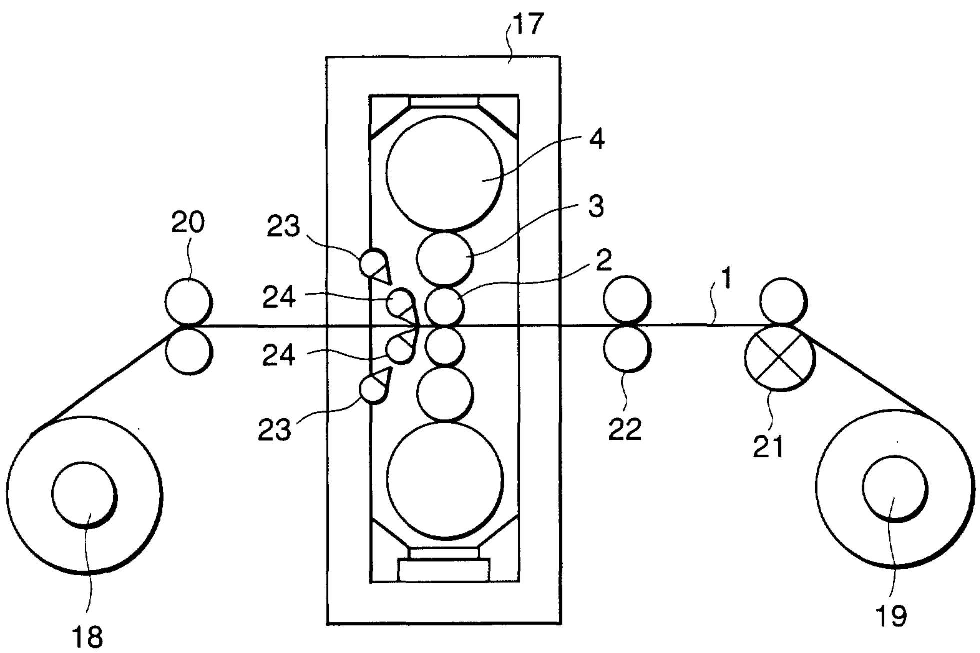

17
4
23
3
20
20
24
2
1
20
22
24
21
22
21
23
18
19
19

FIG. 20


17
4
3
20
23
2
24
1
24
23
22
21
18
19