(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 572 808 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
21.05.2014 Bulletin 2014/21

(51) Int Cl.:
B21B 13/14 *(2006.01)* ***B21B 29/00*** *(2006.01)*

(21) Application number: **12184124.1**

(22) Date of filing: **12.09.2012**

(54) **Cold-rolling mill, tandem rolling system, reversing rolling system, modification method of rolling system, and operating method of cold-rolling mill**

Kaltwalzwerk, Tandemwalzsystem, Umkehrwalzsystem, Modifikationsverfahren des Walzsystems und Betriebsverfahren des Kaltwalzwerks

Laminoir à froid, système de laminage en tandem, système de roulement d'inversion, procédé de modification d'un système de roulement et procédé de fonctionnement d'un laminoir à froid

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **20.09.2011 PCT/JP2011/071391**

(43) Date of publication of application:
27.03.2013 Bulletin 2013/13

(73) Proprietor: **Mitsubishi-Hitachi Metals Machinery, Inc.**
Tokyo 108-0014 (JP)

(72) Inventors:
- **Yasunari Shinichi**
  Tokyo, 108-0014 (JP)
- **Shimaya, Fumihisa**
  Hiroshima, 733-8553 (JP)

(74) Representative: **Beetz & Partner Patentanwälte**
Steinsdorfstraße 10
80538 München (DE)

(56) References cited:
EP-A2- 0 154 896
DE-A1- 10 208 389
JP-A- 11 179 408
JP-A- 59 185 508

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 2 572 808 B1

Printed by Jouve, 75001 PARIS (FR)

Description

Technical Field

[0001] The present invention relates to a cold-rolling mill, a tandem rolling system, a reversing rolling system, a modification method for a rolling system, and an operating method for a cold-rolling mill. A cold-rolling mill as described in the preamble portion of patent claim 1 has been known from DE 102 08 389 A1.

Background Art

[0002] For the rolling systems that range nearly 1,500-1,900 mm in maximum strip width of the system specifications, according to actual results, mild steel strips and/or high strength steel strips are produced in large quantities by the tandem rolling systems of four-high or six-high rolling mills with work roll diameters nearly of 420-630 mm. This fact can be verified from the system specifications shown in Non-Patent Document 1, for example.

[0003] On the other hand, to meet the needs for rolling harder steel strips and for rolling at higher reduction ratios, it is effective to reduce the work roll diameter of the rolling mill. Such a cluster type rolling mill as described in Patent Document 1 exists as a typical example of rolling mills whose work roll diameters range up to nearly 200 mm. These rolling mills are advantageous for producing very hard steel strips such as stainless steel strips and electromagnetic steel strips.

Prior Art Documents

Patent Documents

[0004]

Patent Document 1: JP-3034928 A
Non-Patent Documents

[0005] Non-Patent Document 1: "Cold Strips Manufacturing Equipment Specifications and Plant Equipment Layout in Japan", compiled/revised by the Iron and Steel Institute of Japan (Collaborative Research Workshop, Working Group on Steel Strips, Sub-Committee on Cold-Rolled Steel Strips)

Non-Patent Document 2: Textbook of the 101st Lecture on Plastic Working, "Basics and Application of Strip Rolling - Crown and Flatness", pp. 62, Fig. 1.3.2, published by the Japan Society for Technology of Plasticity)
DE 102 08 389 A1 discloses a cold-rolling mill for rolling a steel strip of minimum width not less than 600 mm and maximum width not less than 1,500 mm but not greater than 1,900 mm, the mill comprising a pair of upper and lower work rolls; a pair of upper and lower intermediate rolls supporting the work rolls, respectively; a pair of upper and lower buck-up rolls supporting the intermediate rolls, respectively; an axial direction roll shifting device for each of the intermediate rolls; and bending devices for each of the work rolls and the intermediate rolls; wherein the work rolls each have a diameter not less than 300 mm but not greater than 400 mm.

Summary of the Invention

Problem to be Solved by the Invention

[0006] For the rolling systems that range nearly 1,500-1,900 mm in the maximum strip width of the system specifications, the mild steel strips and/or high strength steel strips mainly used for automobiles are produced in large quantities by the tandem rolling systems of the four-high or six-high rolling mills with the work roll diameters nearly of 420-630 mm. In recent years, the demand for these steel strips is expanding particularly in high strength steel strip markets. There also are growing needs for harder high strength steel strips than ever, and for rolling high strength steel strips of the same hardness as before at higher reduction ratios. The two methods discussed below are conceivable to address the needs for rolling harder steel strips and for rolling at higher reduction ratios.

[0007] A first method is to reduce the work roll diameter of the rolling mill. The cluster type rolling mill discussed earlier herein as a typical rolling mill having a work roll diameter of 200 mm or less is an example of such a rolling mill.

[0008] However, rolling mills that employ small-diameter work rolls, such as the cluster type rolling mill, are unsuitable for mass production and one cannot expect high productivity from these mills.

[0009] A second method is to increase the number of stands of tandem rolling mills of conventional specifications.

Even if one stand remains unchanged in rolling capabilities, increasing the number of stands improves a total rolling reduction capability of the tandem rolling mill. In other words, it becomes possible, while maintaining a feature of high productivity of the tandem rolling mill, to roll harder steel strips and to implement rolling at higher reduction ratios. Increase in the number of stands of the rolling mills, however, means significantly increasing an initial investment in new installation work or an additional investment in modification work.

[0010] For these reasons, the conventional rolling systems discussed above have posed a decrease in productivity due to the use of a small-diameter work roll mill, a significant increase in costs due to the increase of stands, and other problems, as in the cluster type rolling mill.

[0011] An object of the present invention is to provide a cold-rolling mill, tandem rolling system, reversing rolling system, rolling system modification method, and cold-rolling mill operating method in which, by reducing the work roll in diameter, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed, while preventing decrease in productivity due to the use of the small-diameter work roll mill as used in the cluster type rolling mill.

[0012] Another object of the present invention is to provide a cold-rolling mill, tandem rolling system, rolling system modification method, and cold-rolling mill operating method in which high productivity as of the conventional tandem rolling system can be maintained and without increasing the stands, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed.

Means for Solving the Problems

[0013] To attain the above object, a first aspect of the present invention provides a cold-rolling mill for rolling a steel strip of minimum width not less than 600 mm and maximum width not less than 1,500 mm but not greater than 1,900 mm, the mill including: a pair of upper and lower work rolls; a pair of upper and lower intermediate rolls supporting the work rolls, respectively; a pair of upper and lower buck-up rolls supporting the intermediate rolls, respectively; an axial direction roll shifting device for the intermediate roll; and bending devices for each of the work rolls and the intermediate rolls, wherein the work rolls each have a diameter not less than 300 mm but not greater than 400 mm, and the intermediate rolls each have a diameter not less than 560 mm but not greater than 690 mm.

[0014] The present inventors, after studying combinations of roll diameters that allow in a six-high cold-rolling mill a strip shape to be appropriately maintained and a contact pressure between rolls to be maintained within a allowable range (critical), have discovered such a combination of work roll diameters and intermediate roll diameters as mentioned above, and have thus found it to be possible to obtain a higher reduction ratio than the prior art. As a result, rolling of a harder steel strip than ever to be rolled and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed.

[0015] Because of the six-high rolling mill, it is also possible to prevent a decrease in productivity due to the use of such a small-diameter work roll mill as in the cluster type rolling mill.

[0016] Additionally, when a tandem rolling system is constructed using at least one stand of a cold-rolling mill according to the present invention, by using work rolls smaller than conventional ones in diameter, high productivity as of the conventional tandem rolling system can be maintained and without increasing the stands, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed.

[0017] A second aspect of the present invention provides the cold-rolling mill wherein in the first aspect of the invention, a work roll drive unit for rotationally driving the work rolls is provided as a drive unit for the rolling mill.

[0018] The driving of the work roll causes no potential slipping between rolls, compared with indirect drive of the intermediate roll or buck-up roll.

[0019] Furthermore, even if strip breakage occurs and the broken steel strip becomes jammed between the upper and lower work rolls or becomes wound around one work roll to bring the work roll abruptly stopped, by providing the work roll drive unit with an overload preventive device, the overload preventive device is immediately activated to enable the rolling mill to be stopped.

[0020] Moreover, the rolling mill is free of a driving tangential force likely to be exerted upon the work roll in case of the intermediate-roll drive, and this prevents the work roll from deflecting in a horizontal direction and thus enables the rolling mill to develop its original shape control ability.

[0021] A third aspect of the present invention provides the cold-rolling mill wherein in the second aspect of the invention, the work roll drive unit includes gear spindles adapted to transmit a driving force of an electric motor to each of the work rolls.

[0022] With such a feature, even if the spindle diameter is the same, a larger transmission torque can be attained compared with a universal joint.

[0023] A fourth aspect of the present invention provides the cold-rolling mill wherein in the second or third aspect of the invention, the work roll drive unit includes an overload preventive device adapted to prevent damage to the spindles.

[0024] With such a feature, even if strip breakage occurs and the broken steel strip becomes jammed between the upper and lower work rolls or becomes wound around one work roll to overload the work roll, the overload preventive

device is immediately activated to enable the rolling mill to be stopped without damaging the spindle.

[0025] A fifth aspect of the present invention provides the cold-rolling mill wherein in any one of the first to fourth aspects of the invention, the rolling mill further includes a roll offset device adapted to offset either one of the work rolls and the intermediate rolls relative to axes of the other rolls to an entry or exit side in a rolling direction.

[0026] With such a feature, the horizontal deflection of the work roll in a rolling direction can be suppressed as small as possible, so that more stable mill operation can be assured.

[0027] A sixth aspect of the present invention provides the cold-rolling mill wherein in the first aspect of the invention, an intermediate roll drive unit for rotationally driving the intermediate rolls is provided as a drive unit for the rolling mill.

[0028] With such a feature, since the intermediate roll is usually designed so as to be larger than the work roll in diameter, the drive spindle can be designed as well so as to stay within a range of the intermediate roll diameter. This enables a drive spindle of the drive unit to be manufactured to sufficient strength against a necessary torque.

[0029] A seventh aspect of the present invention provides the cold-rolling mill wherein in the sixth aspect of the invention, the intermediate roll drive unit includes universal joints adapted to transmit a driving force of an electric motor to each of the intermediate rolls.

[0030] With such a feature, the roll drive unit can be manufactured at a lower cost than in a case that it uses a gear spindle.

[0031] An eighth aspect of the present invention provides the cold-rolling mill wherein in the sixth or seventh aspect of the invention, the rolling mill further includes a roll offset device adapted to offset either one of the work rolls and the intermediate rolls relative to axes of the other rolls to an entry or exit side in a rolling direction.

[0032] With such a feature, the horizontal deflection of the work roll in a rolling direction can be suppressed as small as possible, so that more stable mill operation can be assured.

[0033] A ninth aspect of the present invention provides a tandem rolling system comprises a row of plural stands of rolling mills, wherein the plural stands of rolling mills include at least one stand of the cold-rolling mill according to any one of the first to eighth aspects of the present invention.

[0034] The plural stands of rolling mills may be all the cold-rolling mill according to any one of the first to eighth aspects of the present invention.

[0035] With such features, high productivity as of the conventional tandem rolling system can be maintained and without increasing the stands, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed.

[0036] A tenth aspect of the present invention provides a reversing rolling system comprising at least one reversing rolling mill, wherein the reversing rolling mill includes at least one cold-rolling mill according to any one of the first to eighth aspects of the present invention.

[0037] With such a feature, in the reversing rolling system, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed, while preventing decrease in productivity due to the use of the small-diameter work roll mill as used in the cluster type rolling mill.

[0038] An eleventh aspect of the present invention provides a modification method of a rolling system having one or plural stands of rolling mills, the method comprising modifying at least one stand of the rolling mill into the cold-rolling mill according to any one of the first to eighth aspects of the present invention.

[0039] With such a feature, in the tandem rolling system, high productivity as of the conventional tandem rolling system can be maintained and without increasing the stands, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed.

[0040] In addition, in the reversing rolling system, by utilizing the existing system, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed.

[0041] A twelfth aspect of the present invention provides an operating method of a cold-rolling mill, the method comprising rolling the steel strip at a reduction ratio higher than 12% by using the cold-rolling mill according to any one of the first to eighth aspects of the present invention.

Effects of the Invention

[0042] In accordance with the present invention, by reducing the work roll in diameter, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed, while preventing decrease in productivity due to the use of the small-diameter work roll mill as used in the cluster type rolling mill.

[0043] Additionally, in accordance with the present invention, high productivity as of the conventional tandem rolling system can be maintained and without increasing the stands, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed.

Brief Description of the Drawings

[0044]

[Fig. 1]
Fig. 1 is a side view of a six-high rolling mill. [Fig. 2]
Fig. 2 is an external view of the six-high rolling mill, taken from a direction of arrow A in Fig. 1. [Fig. 3]
Fig. 3 is an external view of the six-high rolling mill, taken from a direction of arrow B in Fig. 1. [Fig. 4]
Fig. 4 is a graph that represents critical rolling loads at which an appropriate strip shape is retainable by combining various intermediate roll diameters for work rolls in order to find a maximum load at which the appropriate strip shape is retainable.
[Fig. 5]
Fig. 5 is a diagram that shows calculated simulation results on allowable rolling loads, derived from contact pressures between rolls allowed from roll strength in the combinations of work roll diameters and corresponding optimal intermediate roll diameters in Fig. 4.
[Fig. 6]
Fig. 6 is a diagram that shows the critical rolling loads at which the appropriate strip shape is maintainable in the combinations of work roll diameters and corresponding optimal intermediate roll diameters that were obtained in Fig. 4, the rolling load data being additionally shown with the calculation results in Fig. 5.
[Fig. 7]
Fig. 7 is a diagram that shows calculated simulation results on reduction ratios which were obtained for each work roll diameter under the allowable rolling loads derived from Fig. 6, the calculation results being additionally shown with the load data in Fig. 6.
[Fig. 8]
Fig. 8 is a diagram that shows results of studies which, in combinations of different fixed intermediate roll diameters and various work roll diameters, were conducted in a manner similar to that of Fig. 7.
[Fig. 9]
Fig. 9 is a diagram that shows results of studies which, in combinations of work roll diameters and corresponding appropriate intermediate roll diameters, were conducted with two different strip widths, 600 mm and 1,900 mm, in a manner similar to that of Fig. 7.
[Fig. 10]
Fig. 10 is a diagram that shows comparative study results on the number of stands required for 780-MPa high strength steel strip rolling with 340-mm diameter work rolls and with conventional 475-mm diameter work rolls.
[Fig. 11]
Fig. 11 is a diagram that shows comparative study results on reduction ratios at respective stands and cumulative reduction ratios for 780-MPa high strength steel strip rolling with the 340-mm diameter work rolls and with the conventional 475-mm diameter work rolls.
[Fig. 12]
Fig. 12 is a diagram that shows comparative study results on the number of stands required for 1,180-MPa high strength steel strip rolling with the 340-mm diameter work rolls and with the conventional 475-mm diameter work rolls.
[Fig. 13]
Fig. 13 is a diagram that shows comparative study results on reduction ratios at respective stands and cumulative reduction ratios for 1,180-MPa high strength steel strip rolling with the 340-mm diameter work rolls and with the conventional 475-mm diameter work rolls.
[Fig. 14] Fig. 14 is an external view that shows a drive system of a work roll drive type, the external view having been taken from a side of the rolling mill.
[Fig. 15]
Fig. 15 is a schematic longitudinal view showing a gear spindle in section.
[Fig. 16A]
Fig. 16A is a schematic longitudinal view showing a universal joint in section.
[Fig. 16B]
Fig. 16B is a sectional view taken along line A-A in Fig. 16A.
[Fig. 17]
Fig. 17 is a diagram representing a relationship between an outer diameter of a spindle coupling and a maximum transmittable torque.
[Fig. 18A]
Fig. 18A is an illustration that shows general layout of coupling portions of upper and lower paired spindles.
[Fig. 18B]
Fig. 18B is an illustration that shows layout of coupling portions for improved spindle strength.
[Fig. 19A]
Fig. 19A is an illustration that shows a work roll drive unit provided with a spindle type of hydraulic torque limiter as an overload preventive device.

[Fig. 19B]
Fig. 19B is an illustration that shows a work roll drive unit provided with a coupling type of hydraulic torque limiter as an overload preventive device.
[Fig. 19C]
Fig. 19C is an illustration showing a configuration in which a coupling for connecting an output shaft of a gearbox to an electric motor is provided with a shear pin as an overload preventive device.
[Fig. 20A]
Fig. 20A is a diagram showing a work roll offset method.
[Fig. 20B]
Fig. 20B is a diagram showing an intermediate roll offset method.
[Fig. 21]
Fig. 21 is an external view that shows a drive system of an intermediate roll drive type, the external view having been taken from a side of the rolling mill.
[Fig. 22]
Fig. 22 is a diagram showing an embodiment of a tandem rolling system constructed using a cold-rolling mill of the present invention.
[Fig. 23]
Fig. 23 is a diagram showing an embodiment of a reversing rolling system constructed using a cold-rolling mill of the present invention.
[Fig. 24]
Fig. 24 is a diagram showing an example of modifying a tandem rolling system using a cold-rolling mill of the present invention.
[Fig. 25]
Fig. 25 is a diagram showing another example of modifying a tandem rolling system using a cold-rolling mill of the present invention.
[Fig. 26]
Fig. 26 is a diagram showing an appropriate strip shape.
[Fig. 27]
Fig. 27 is a diagram showing a strip shape considered not to be appropriate.

Modes for Carrying Out the Invention

[0045] As discussed earlier herein, the mild steel strips and/or high strength steel strips used primarily for automobiles are required to be mass-produced. Traditionally, therefore, four-high or six-high rolling systems of a tandem type with rolls arranged in a row have been employed and as previously discussed, respective work roll diameters have ranged nearly from 420 to 530 mm. However, needs for rolling harder high strength steel strips than ever, and those of rolling high strength steel strips of the same hardness as before at higher reduction ratios, are increasing. Further, to respond to these needs, the diameters of the work rolls in tandem rolling mills need reducing below conventional roll diameters.

[0046] Trends and current situations associated with the reducing of the work roll diameter in tandem rolling mills that underlies the present invention are described below.

[0047] The fact that work roll diameters nearly from 420 to 530 mm have been traditionally used is as discussed above, and from a historical perspective, work roll diameters are changing each year and have a tendency to be reduced, which is shown in Non-Patent Document 2. This tendency is deemed to imply growing market needs for thinner, harder steel strips. For automotive use of the mild steel strips and/or high strength steel strips for which the present invention is targeted, it is being demanded under globally growing awareness of the importance of environment conservation that reduction in vehicle body weight for an improvement of fuel efficiency and an improvement of strength for higher on-crashworthiness safety be ensured at the same time, and the needs for thinner and harder steel strips are growing. It is a natural movement, therefore, that the work rolls in rolling mills be reduced in diameter to meet those needs, but in fact, actual work roll diameters still remain in the range mentioned above.

[0048] One of its main causes would be that sufficient studies have traditionally not been conducted upon a relationship between the reducing of the work roll diameter in tandem rolling mills and rolling reduction capabilities of the rolling mills. The present inventors have focused attention upon the rolling reduction capabilities of the rolling mills for reduction of work roll diameter in a tandem rolling mill, and synthetically studied influences of work roll diameters imposed on contact pressures between rolls and shape controllability as well as the reduction ratio. As a result, the inventors have gained a new knowledge of an optimal work roll diameter range being present for the rolling reduction capabilities, and have confirmed from this knowledge that work rolls can be reduced in diameter by 20-25 % in comparison with actual data that was obtained in conventional products.

[0049] Hereunder, derivation of optimal work roll diameters, focused upon the reduction in diameter, will be described

in detail.

[0050] First, a configuration of a six-high cold-rolling mill according to the present invention is described below using Figs. 1 to 3. Fig. 1 is a side view of the six-high rolling mill, and Figs. 2 and 3 are external views of the six-high rolling mill, taken from directions of arrows A and B, respectively, in Fig. 1.

[0051] As shown in Fig. 1, the six-high rolling mill 51 includes: a pair of upper and lower work rolls 2 for rolling a material to be roll (steel strip) 1 that is a metallic material by coming into direct contact therewith; a pair of upper and lower intermediate rolls 3 supporting the work rolls 2, respectively; and a pair of upper and lower buck-up rolls 4 supporting the intermediate rolls 3, respectively. Bearing housings 8 and 9 are mounted at ends of each of the work rolls 2 and the intermediate rolls 3, and as shown in Fig. 2, work roll bending devices 10 and intermediate roll bending devices 11 are arranged to bend the work rolls and the intermediate rolls by exerting a vertical force upon the bearing housings 8 and 9. Housings 5 function as a support structure that uses bearing housings 6 of the buck-up rolls 4.

[0052] At a lower region of each housing 5 is installed a hydraulic screw down device 7 as rolling reduction means, which moves the bearing housing 6 of each lower buck-up roll 4 vertically to reduce the thickness of the material 1 to be rolled.

[0053] The work roll bending devices 10 can provide the work rolls with increase bending and decrease bending.

[0054] At the upper and lower paired intermediate rolls 3, roll shifting devices 23 (see Fig. 3) are mounted so as to enable the intermediate rolls to move in an axial direction of the rolls. An example of a roll shifting device 23 is described below using Fig. 3. The bearing housing 9 of each intermediate roll 3 is sandwiched between intermediate roll offset devices 19, and the intermediate roll offset devices 19 are each fitted in a project block 17 and mounted in a shift block 12 movable in the roll axial direction. Here, each of the intermediate roll offset devices 19 is placed to move the intermediate roll 3 in a horizontal direction and change a relative position of the intermediate roll 3 with respect to the corresponding work roll 2. The details of the arrangement, purpose and operation of the intermediate roll offset device 19 will be explained later. At a driving side, the shift blocks 12 are coupled to the intermediate roll bearing housing 9 via keeper plates 14 each actuated by a hydraulic cylinder 15, and the shift blocks 12 at an operating side are coupled to the shift blocks 12 of the driving side via stays 18. This integrates the intermediate roll 3 and the shift blocks 12. Hydraulic cylinders 16 are installed on shift frames 24 fixed to the housings 5, and are coupled to the shift blocks 12 at the driving side. With such an arrangement, by driving the hydraulic cylinders 16, the intermediate roll 3 and the shift blocks 12 can be moved to a desired position in the roll axial direction. In particular, since each intermediate roll offset device 19 contains an intermediate roll bending device 11, a point at which a bending force acts remains unchanged, even when the intermediate roll 3 is shifted in the roll axial direction and/or the intermediate roll 3 is moved in the horizontal direction.

[0055] Additionally in the present embodiment, as shown in Fig. 1, a tapered chamfer 3a nearly of 1,000 R is provided at the end of each intermediate roll 3. A distance from a starting point of the chamfer 3a and an end of the material 1 to be rolled is termed "UCδ". The UCδ is expressed with a plus sign when the starting point of the chamfer 3a is positioned outside of the strip end and with a minus sign when the starting point is positioned inside of the strip end.

[0056] The results of simulation that is made by using the above mentioned rolling mill 51 as a model are explained below.

[0057] The wording of "appropriate strip shape" that is used in the subsequent description is first defined here. In the present invention, rolled-strip crown shapes were simulated in various combinations of work roll diameters, intermediate roll diameters, and strip widths, and critical rolling loads at which the thus-obtained strip crown shapes can satisfy the following conditions are each expressed as the "critical rolling load enabling a strip shape to be maintained appropriately", and the strip shape at that time is defined as the "appropriate strip shape".

That is to say,

$$h(0) \geq h(x) \qquad (0 \leq x \leq b) \qquad \ldots \text{ Expression 1}$$

and

$$\delta h(x) = 0 \qquad (0 < x \leq 2/3b) \qquad \ldots \text{ Expression 2,}$$

where

x: coordinates in a direction of the strip width with an origin set at a central portion of the strip width,
b: half the strip width B,
h(x): exit side strip thickness at the position of "x", and

δh(x): amount of strip crown at the position of "x" (= h(0) - h(x)) (mm).

[0058] Figs. 26 and 27 show more specific examples. The appropriate strip shape is such a strip crown shape as shown in Fig. 26, in which, a portion of the strip other than a central portion is the same in thickness as the central portion or smaller in thickness than the central portion (expression 1), and in which up to the position of 2/3 of the strip width from the center thereof, the strip crown is zero (expression 2). Conversely as shown in Fig. 27, a shape in which the portion of the strip other than the central portion is greater in thickness than the central portion or in which the strip crown is not zero from a position more central than the position of 2/3 of the strip width from the center thereof (expression 2), is not considered to be the appropriate strip crown shape.

[0059] Next, the simulation results are described below. High strength steel strips of 1,650 mm in strip width were used as strip materials. First, Fig. 4 is a graph that represents the critical rolling loads enabling the strip shape to be maintained appropriately in combinations of various intermediate roll diameters for work rolls. The horizontal axis represents the intermediate roll diameters, and the vertical axis represents rolling loads (here, rolling load per strip width: tons/mm). A certain intermediate roll diameter was varied for each of work roll diameters of 250 mm, 300 mm, 330 mm, 340 mm, 380 mm, 400 mm, 450 mm, and 475 mm, and the critical rolling loads enabling the strip shape to be maintained appropriately were calculated. Data that was obtained using the work rolls of 330 mm and 340 mm in diameter is shown as one integrated set of data since there was substantially no difference between both. This results in the following being derived. Data in parentheses in Fig. 4 is optimal intermediate roll diameters for each work roll diameter.

[0060]

1. For example, for the work roll diameter of 475 mm, when the intermediate roll diameter is increased in order from 500 mm, a maximum value of the rolling load enabling the strip shape to be maintained appropriately increases for up to 580 mm, but once 580 mm has been exceeded, the maximum value of the rolling load enabling the strip shape to be maintained appropriately unchanged, even for whatever intermediate roll diameter greater than 580 mm, that is, the effect of increasing the intermediate roll diameter only flattens.
In this case, the smallest possible roll diameter will be selected by considering initial roll-manufacturing costs and subsequent running costs in the actual plant operation. In addition, increasing the roll diameter is not preferable in terms of system investment since the increase in the roll diameter results in increase in overall rolling-mill dimensions. Therefore, the intermediate roll diameter of 580 mm is optimal for the work roll diameter of 475 mm. Optimal intermediate roll diameters are also derived for other work roll diameters.
2. As the work roll diameter is reduced, the optimal intermediate roll diameter will be larger. This is because a greater intermediate roll diameter will be required in order to compensate for a decrease in rigidity of the work rolls themselves against the load, with the decrease in the work roll diameter.
3. The rolling load enabling the strip shape to be maintained appropriately tends to lower with decreasing work roll diameter. This is because, as the work roll diameter decreases, effectiveness of the work roll bender will extend only to a portion around the strip edge.

[0061] Allowable rolling loads (here, each load per unit strip width, in tons/mm) in the combinations of work roll diameters and corresponding optimal intermediate roll diameters in Fig. 4 were calculated by simulation based on contact pressures (Hertz stresses) between rolls allowed from roll strength. Results of the simulation are shown in a graph of Fig. 5. The vertical axis represents the work roll diameters, and the horizontal axis represents the rolling loads (load per strip width: tons/mm). An increase in contact pressures (Hertz stresses) between rolls causes rolling contact fatigue, thereby leading to the roll surface spalling and/or to other problems occurring. During the simulation, studies were conducted from a viewpoint of preventing these problems from occurring.

[0062] According to the studies, there is a tendency for a allowable rolling load to increase as the work roll diameter decreases. In general, a critical contact pressure at the roll is deeply associated with hardness of the roll, and an allowable contact pressure increases with increasing hardness. Since the buck-up rolls, the intermediate rolls, and the work rolls are usually manufactured to higher hardness levels in that order, the allowable contact pressure also increases in that order. Conversely, the contact pressures between rolls are each dictated (geometrically) by a combination of the roll diameters, and the contact pressures between rolls increase with decreasing diameter. Referring to Fig. 5, as set forth in Fig. 4, the optimal intermediate roll diameters for each work roll diameter increase with decreasing work roll diameter. This causes the allowable load to increase with decreasing work roll diameter, in Fig. 5. In other words, as a result of studying the contact pressures between the rolls and strength of each roll, the strength of the buck-up roll became a bottleneck and as the intermediate roll diameter increased, the contact pressure between the intermediate roll and the buck-up roll lowered, for which reason, the tendency shown in Fig. 5 appeared.

[0063] The critical rolling loads enabling the strip shape to be maintained appropriately in the combinations of work roll diameters and corresponding optimal intermediate roll diameters that were obtained in Fig. 4, were calculated and results of the calculation were added to the graph of Fig. 5. The result is Fig. 6. An allowable rolling loads to serve as

indicators for actual rolling are obtained from Fig. 6. That is to say, the smaller of data in two graphs of Fig. 6 is the allowable rolling loads for the work roll diameter. For example, it follows from the limits of contact pressure that the allowable rolling load for the work roll diameter of 475 mm is nearly 1.22 tons/mm, and it follows from the limits of strip shape that the allowable rolling load for the work roll diameter of 250 mm is nearly 0.95 ton/mm.

[0064] Rolling reduction ratios obtained for different work roll diameters under the above-obtained allowable rolling loads were calculated and then added to the data of Fig. 6. The result is Fig. 7. The vertical axis in the right side as shown represents the rolling reduction ratios (%).

[0065] According to Fig. 7, as the work roll diameter decreases from 475 mm, the rolling reduction ratio obtained increases progressively, then before too long, peaking in a neighborhood of the 340-mm work roll diameter. It can also be seen that further reducing the work roll diameter lowers the rolling reduction ratio on the contrary. It can be additionally seen that while the rolling reduction ratio remains substantially equal, nearly 14.5-15.0 %, in a work roll diameter range of 300-400 mm, the rolling reduction ratio decreases more for both of work roll diameters smaller than 300 mm, and those greater than 400 mm. The rolling reduction ratios of about 14.5-15.0 %, obtained in the work roll diameter range of 300-400 mm, are nearly 21-25 % as high as those of about 12% obtained for conventional work roll diameters. After thus conducting synthetic reviews from both standpoints of the limits of the rolling load enabling the strip shape to be maintained appropriately, and the limits of the rolling load restricted from the contact pressures between rolls, the present inventors have found that the work roll diameters of 300-400 mm are appropriate in that a high rolling reduction ratio can be obtained.

[0066] In addition, if ±5% of the work roll diameter of 340 mm at which the rolling reduction ratio peaks is selected, the work roll diameters range nearly 320-360 mm, in which case, it can be seen that high rolling reduction ratios nearly of 15.0%, substantially equal to the peak value of the rolling reduction ratio, are obtainable. In terms of obtaining a higher rolling reduction ratio, therefore, the present inventors have found it optimal that the work roll diameter be confined to a range of 320-360 mm (nearly 340± 5%).

[0067] The above is the study results relating to the critical rolling loads for the contact pressures between rolls (Fig. 5), the critical rolling loads for the strip shape (Fig. 6), and rolling reduction ratios (Fig. 7), in combinations of work roll diameters and optimal intermediate roll diameters. The intermediate roll diameter used, however, does not always need to be an optimal value. That is to say, as described above, the appropriate work roll diameter range in the present invention is 300-400 mm, and the facts that the optimal intermediate roll diameter for the work roll diameter of 300 mm is 630 mm and that the optimal intermediate roll diameter for the work roll diameter of 400 mm is 600 mm are as shown in Fig. 4. For the work roll diameter of 400 mm, if the intermediate roll diameter is at least 600 mm, effects equivalent to those achievable for 600 mm can also be obtained. This means that a minimal intermediate roll diameter necessary to obtain maximal effects for work rolls of 300-400 mm is 600 mm or 630 mm, whichever is the greater, and that 630 mm, in particular, is more preferable for better results. Rolls, on the other hand, have their operating ranges, which are generally some 10%. It follows from this that the intermediate roll diameter of 630 mm x 1.1 times is about 690 mm, from which it would be fair to say that maximum allowable intermediate roll diameters of 630-690 mm for the work roll diameters of 300-400 mm are optimal.

[0068] Fig. 8 is a diagram that shows results of studies which, in combinations of different fixed intermediate roll diameters and various work roll diameters, were conducted in a manner similar to that of Fig. 7. The intermediate roll diameters are 530 mm, 550 mm, 560 mm, 630 mm, and 690 mm. Fig. 8 indicates that as described above as to the study results on the critical rolling loads for the contact pressures between rolls, the critical rolling loads for the strip shape, and rolling reduction ratios allowed in the combinations of work roll diameters and optimal intermediate roll diameters, when the intermediate roll diameter is varied in the range of 630-690 mm, the peak value of the rolling reduction ratio can be obtained in the work roll diameter range of 300-400 mm. In addition, to define a lower limit of the intermediate roll diameter, providing a determination criterion dictating that an intermediate roll diameter exceeding the rolling reduction ratio of about 12% obtainable in the conventional combination of the 475-mm work roll diameter and the 580-mm intermediate roll diameter should be adopted to obtain an effect in the work roll diameter range of 300-400 mm allows one to see that 560 mm is the lower limit of the intermediate roll diameter. In this case, it is judged from Fig. 8 that in a neighborhood of the 300-mm work roll diameter, since the rolling reduction ratio obtainable is smaller than 12%, the intermediate roll diameter of 550 mm is inappropriate.

[0069] It follows from the above that the appropriate intermediate roll diameter range for the work roll diameters of 300-400 mm is 560-690 mm.

[0070] Figs. 4 to 8 apply to a case in which the strip material is a high strength steel strip of 1,650 mm in strip width, and Fig. 9 is a diagram that shows results of studies which, in combinations of work roll diameters and corresponding optimal intermediate roll diameters, were conducted with two different strip widths, 600 mm and 1,900 mm, in a manner similar to that of Fig. 7. As can be seen from Fig. 9, a tendency can be obtained that even when the strip width is varied in 600 mm-1,900 mm, the rolling reduction ratio remains at a high level in the work roll diameter range of 300-400 mm, as in the case of the 1,650-mm strip width, according to the study results on the critical rolling loads for the contact pressures between rolls, the critical rolling loads for the strip shape, and rolling reduction ratios.

[0071] The buck-up roll diameter that was used for the simulation is 1,370 mm, which is adopted in the conventional rolling mills ranging nearly 1,500-1,900 mm in maximum strip width. However, the buck-up roll diameter of 1,370 mm is just an example, and any other buck-up roll diameter may be used, only if it is determined from the buck-up roll neck diameter and neck bearing size enabling a rolling mill of the above strip widths to support a maximum necessary rolling load. In this case, the tendency of changing critical rolling loads and rolling reduction ratios in the combinations of work roll diameters and corresponding optimal intermediate roll diameters in Figs. 4 to 9 also remains invariant. In comparison with the same buck-up roll diameter, as in the case of using the 1,370-mm buck-up roll diameter, a higher reduction ratio can be achieved in the present invention than in the conventional combinations of work roll diameters and intermediate roll diameters.

[0072] Beneficial effects by applying to a tandem rolling system the rolling mill which employs the 340-mm work rolls where the rolling reduction ratio nearly peaks in the work roll diameter range of 300-400 mm are next described below. The optimal intermediate roll diameter in this case is 620 mm, according to Fig. 4. In the prior art to which the present invention forms a contrast, on the other hand, the optimal intermediate roll diameter in a tandem rolling system with 475-mm diameter work rolls is 580 mm, according likewise to Fig. 4.

[0073] Fig. 10 is a diagram that shows comparative study results on the number of stands required for 780-MPa high strength steel strip rolling with the 340-mm diameter work rolls and with prior-art 475-mm diameter work rolls. Looking at the smaller values of the allowable rolling loads depending on the contact pressures between rolls and the critical rolling load enabling the strip shape to be maintained appropriately, one can see that 1.22 tons/mm is applied when the work roll diameter is 475 mm while 1.13 tons/mm is applied when the work roll diameter is 340 mm. These values are used as indicators for limitation as the allowable rolling loads for each work roll diameter. As a result, it can be seen that for the work roll diameter of 475 mm, desired rolling within the allowable rolling loads is possible by using five stands of rolling mills. For the work roll diameter of 340 mm, on the other hand, the five stands allow desired rolling with margins with respect to the allowable loads, and even four stands reducing one stand also enables desired rolling.

[0074] Study results on rolling reduction ratios at respective stands and cumulative rolling reduction ratios in Fig. 10 are shown in Fig. 11 in comparison between the present invention and the prior art. The data shows a total of four stands in the case of the present invention and a total of five stands in the case of the prior art. Bar graphs represent rolling reduction ratios at the respective stands, which are shown by shading or masking in the case of the present invention, and in outline typeface form (non-shaded or non-masked) in the case of the prior art. These graphs indicate that the present invention provides 4-5 % higher rolling reduction ratios in each stand than the prior art. Line graphs, on the other hand, represent the cumulative rolling reduction ratios after passage through each stand, shown with a solid line in the case of the present invention and with a dashed line in the case of the prior art. By comparison of both, upon passage through three stands, the present invention provides cumulative rolling reduction ratios as high as about 10%, over figures of the prior art, the fact of which explicitly indicates that the number of stands can be reduced in the invention.

[0075] Fig. 12 shows comparative study results on the number of stands required for 1,180-MPa high strength steel strip rolling with the 340-mm diameter work rolls and with the prior-art 475-mm diameter work rolls. Firstly, in the case of the 475-mm diameter work rolls, if the rolling is tried with five stands, when the rolling loads at each stand are controlled successively from the preceding stands to stay within a tolerance, the load at the final fifth stand will inevitably increase, which will end in desired rolling being infeasible. If the number of stands is increased to six, the loads at all stands can be controlled to stay within the tolerance, thus making rolling possible. In the case of the work roll diameter of 340 mm, on the other hand, desired rolling is possible at five stands, which yields a great advantage that one stand can be saved in comparison with the prior-art 475-mm diameter work rolls. Comparison of rolling reduction ratios at respective stands and cumulative rolling reduction ratios in Fig. 12, between the present invention and the prior art, are shown in Fig. 13 in a format similar to that of Fig. 11. The data shows a total of five stands in the case of the present invention and a total of six stands in the case of the prior art. Bar graphs represent rolling reduction ratios in respective stands, which are shown by shading or masking in the case of the present invention, and in outline typeface form (non-shaded or non-masked) in the case of the prior art. These graphs indicate that the present invention provides 2-3 % higher rolling reduction ratios in each stand than the prior art does. Line graphs, on the other hand, represent the cumulative rolling reduction ratios after passage through each stand, shown with a solid line in the case of the present invention and with a dashed line in the case of the prior art. By comparison of both, upon passing through four stands, the present invention provides cumulative rolling reduction ratios as high as about 8%, over figures of the prior art, the fact of which explicitly indicates that the number of stands can be reduced in the invention.

[0076] As is evident from the above, the present invention enables rolling at reduction ratios higher than those obtainable in the prior art, and can even enjoy a great advantage in that the number of stands in a tandem rolling system can be reduced.

[0077] While the cold-rolling mill of the present invention may adopt either work roll drive or intermediate roll drive as the drive type for the rolling mill, work roll drive is preferred for the following reasons.

[0078] Since work roll drive directly drives the work rolls that roll the steel strip, this drive type is not likely to cause inter-roll slipping, compared with indirect drive of the intermediate rolls or the buck-up rolls. In addition, work roll drive

as viewed from a standpoint of tandem rolling system operation is described below. If strip breakage occurs, the broken steel strip may become jammed between the upper and lower work rolls or become wound around one work roll, thus bringing the work roll(s) into an abrupt stop. Once this state has arisen, work roll drive will immediately impose an overload to the drive system that transmits torque from an electric motor to a gearbox (a speed reducer or a reduction gear) first and then to spindles. Overload preventive devices provided midway in the drive system will then be activated to cut off the torque transmitted to the work rolls, and enable the rolling mill to be stopped. These overload preventive devices may be implemented using, for example, hydraulic torque limiters or pins, called shear pins, that will cut off torque in case of overloading. Still another advantage of work roll drive is that because of direct work roll drive, the rolling mill does not develop a driving tangential force likely to be exerted upon the work roll during intermediate roll drive. This characteristic prevents the work roll from deflecting in the horizontal direction. Since the rolling mill prevents the work roll from deflecting in the horizontal direction, the mill can display its original ability to control shape, this characteristic becoming a great advantage in product quality control.

[0079] For intermediate roll drive, on the other hand, since the intermediate rolls are usually designed to have a greater diameter than the work rolls, drive spindles can also be designed to have a diameter staying within the intermediate roll diameter range, and can therefore be manufactured to high enough strength against the torque required. On the contrary, however, in the event of the strip breakage as mentioned above, even after the work roll has come to an abrupt stop, the intermediate roll may continue to rotate while slipping against the work roll, so these rolls are likely to suffer significant damage. In particular, if strip breakage occurs in a tandem rolling mill, adverse effects extend to more than one stand. Additionally, in the case of intermediate roll drive, the driving tangential force acts upon the work roll, causing the work roll to deflect in the horizontal direction. The deflection of the work roll in the horizontal direction leads to the strip shape deteriorating, which in turn poses a big problem associated with product quality.

[0080] The present embodiment, therefore, assigns priority to system operational advantages and employs work roll drive as the drive type for the rolling mill.

[0081] The spindles used for work roll drive are next described below.

[0082] First, the drive system of the cold-rolling mill in the present embodiment is described using Figs. 14 and 15. Fig. 14 is an external view that shows the drive system of the work roll drive type, the external view having been taken from a side of the rolling mill. Fig. 15 is a schematic view showing a gear spindle in longitudinal section.

[0083] Referring to Fig. 14, the cold-rolling mill 51 has a work roll drive unit 21 as its drive. The work roll drive unit 21 includes a pair of upper and lower spindles 20, a gearbox 52, a coupling 53, and an electric motor 54, and a driving force of the motor 54 is transmitted to the upper and lower paired work rolls 2 while the driving speed is decreased or increased at a predetermined rate or not changed in the gearbox 52 and any vertical changes in position is absorbed by means of the upper and lower paired spindles 20.

[0084] The upper and lower paired spindles 20 each include, as shown in Fig. 15, an intermediate shaft 61 and gear couplings 62, 63 provided at both ends of the intermediate shaft 61. The gear couplings 62, 63 include respective sleeves 64, 65 with internal teeth 64a, 65a, respectively, formed therein, and respective Hubs 66, 67 with external teeth 66a, 67a, respectively, formed therein to mesh with the internal teeth 64a, 65a of the sleeves 64, 65. At the side of the sleeves 64, 65 opposite to the intermediate shaft 61, axial recesses 68, 69 of the oval shape in cross-section are formed, and by inserting the respective axial ends of one work roll 2 and an output shaft of the gearbox 52 into the recesses 68, 69, the gear couplings 62, 63 are connected to the work roll 2 and the output shaft of the gearbox 52, respectively.

[0085] Figs. 16A and 16B show a universal joint for comparison purposes. Fig. 16A is a schematic view showing the universal joint in longitudinal section, and Fig. 16B is a sectional view thereof, taken along line A-A in Fig. 16A. The universal joint 20A includes universal joint crosses 72, 73 each fitted with a cross joint 76 at one end of an intermediate shaft 71. At the side of the universal joint crosses 72, 73 opposite to the intermediate shaft 71, axial recesses 74 or 75 of the oval shape in cross-section are formed, and by inserting the respective axial ends of one work roll 2 and an output shaft of the gearbox 52 into the recesses 74, 75, the universal joint crosses 72, 73 are connected to the work roll 2 and the output shaft of the gearbox 52.

[0086] A relationship between a maximum transmittable torque of a spindle of a work roll and an outer diameter of the spindle coupling in a one way tandem rolling mill in the prior art is shown in Fig. 17. A solid line denotes gear spindle data, and a dashed line denotes universal joint data. As can be seen from the figure, given the same outer diameter of the coupling, the gear spindle has an ability to transmit about 1.7 times the torque that the universal joint can.

[0087] In the present embodiment, the diameter of the work rolls is reduced and work roll drive is employed, and resultantly, diameters of the spindles are reduced, so the gear spindle is preferable that can transmit larger torque even if the spindle diameter is reduced.

[0088] Next, methods of obtaining appropriate spindle strength when the work rolls are reduced in diameter are described below using Figs. 18A and 18B. Fig. 18A shows general layout of couplings of upper and lower paired spindles, and Fig. 18B shows layout of couplings that enables spindle strength to be improved. Single-dotted lines in the figures each denote a central position of a gear of one gear coupling.

[0089] In general, the gear couplings of the upper and lower paired spindles 20, located closer to the rolling mill, are

constructed so that as shown in Fig. 18A, axial positions of the upper and lower gear couplings 62 are vertically matched so that the central positions of the gears are vertically aligned.

[0090] Let here a distance from an axial center of the upper spindle to that of the lower spindle be L and let a diameter of each of the couplings 62 be D1.

[0091] In contrast, the gear couplings in the present embodiment are constructed such that as shown in Fig. 18B, the positions of gear couplings 62A of the upper and lower paired spindles 20A are vertically deviated into a staggered manner so that the central positions of the gears are vertically misaligned.

[0092] Let here a distance from an axial center of the upper spindle to that of the lower spindle be L and let a diameter of each of the couplings 62A be D2.

[0093] This arrangement avoids interference between the upper and lower gear couplings 62A, and enables the gear couplings 62A to be made greater in diameter (D2>D1) than the prior-art ones (Fig. 18A), even if the axial distance L between the upper and lower spindles is the same between the present embodiment and the prior art. Thus, each gear coupling 62A, one of the weakest sections of the spindle, can be improved in strength.

[0094] This is very effective for securing spindle strength under a situation that the distance between axes of the upper and lower spindles needs to be reduced along with the reduction in the diameter of the work rolls.

[0095] Although spindles of the gear spindle have been shown and described here by way of example in the present embodiment, substantially the same advantageous effects can also be obtained by applying universal joints.

[0096] Next, the overload preventive devices for preventing the spindles from becoming damaged are described below using Figs. 19A, 19B, and 19C.

[0097] Fig. 19A shows a work roll drive unit provided with hydraulic torque limiters of a spindle type as the overload preventive devices. The work roll drive unit 21A includes the hydraulic torque limiters 85 between the gear couplings 63 of the upper and lower paired spindles 20 and upper and lower output shafts of the gearbox 52, the gear couplings 63 being connected to the upper and lower output shafts of the gearbox 52 via the hydraulic torque limiters 85.

[0098] Fig. 19B shows a work roll drive unit provided with a hydraulic torque limiter of a coupling type as an overload preventive device. The work roll drive unit 21B includes the hydraulic torque limiter 86 between an input shaft of the gearbox 52 and an output shaft of the motor 54. The input shaft of the gearbox 52 is connected to the output shaft of the motor 54 via the coupling 53 and the hydraulic torque limiter 86.

[0099] Fig. 19C shows a configuration in which a coupling for connecting an input shaft of a gearbox to an electric motor is provided with a shear pin as an overload preventive device. The coupling 53 has coupling half-bodies 53c, 53d that each include a flange portion 53a or 53b, and the shear pin 87 is provided on the flange portion 53a, 53b.

[0100] If strip breakage occurs, the broken steel strip may become jammed between the upper and lower work rolls or become wound around one work roll to bring the work roll abruptly stopped. Once this state has arisen, work roll drive will immediately impose an overload to the drive system that transmits torque from the motor 54 to the gearbox 52 and then to the spindles 20. The overload preventive devices (hydraulic torque limiters 85, 86 or shear pin 87) provided midway in the drive system will then be activated to cut off the torque transmitted to the work rolls, and enable the rolling mill to be stopped.

[0101] As set forth above, the overload preventive devices shown in Figs. 19A, 19B, 19C are effective for protecting the spindles under the situation that the strength of the spindles themselves has to be reduced along with the reduction in the diameter of the work rolls.

[0102] While it has been described above that the spindles for which the overload preventive devices are placed are gear spindles, the overload preventive devices may instead be applied to the universal joints.

[0103] As described previously using Figs. 2 and 3, the rolling mill of the present embodiment is provided with the intermediate roll offset devices 19 in the roll shifting devices 23 (see Fig. 3). The intermediate roll offset devices 19 are once again described below.

[0104] Referring to Figs. 2 and 3, one intermediate roll offset device 19 is built in the shift block 12 of each roll shifting device 23. A hydraulic cylinder, a screw jack, a wedge plate, or the like would be useable to actuate the intermediate roll offset device 19.

[0105] The intermediate roll offset device 19 contains the intermediate roll bending device 11 that further provides the intermediate roll with vertical bending. The intermediate roll 3, the shift block 12, and the intermediate roll offset device 19 are constructed to shift in a longitudinal direction of the roll at the same time. The intermediate roll offset device 19 is actuated in the rolling direction by the hydraulic cylinder, the screw jack, the wedge plate, or other means, and an amount of the actuation is detected by a position detector. The upper and lower intermediate roll offset devices 19 in each shifting device 23 are controlled independently or simultaneously.

[0106] The offset device in the present invention is of a layout in which, even if the intermediate roll 3 becomes offset in the rolling direction, the vertical roll-bending device 11 is fixed at a position to always maintain a constant distance "L1" from a central portion of the intermediate roll 3. The offset device is also of a layout in which the intermediate roll offset device 19 and the bearing housing 9 have respective central portions matched in the longitudinal direction of the roll, thereby avoiding an unbalanced load upon an internal bearing of the bearing housing 9.

[0107] The above has described the intermediate roll offset device, but this offset device may be replaced by a work roll offset device. Obviously, this work roll offset device, as with the intermediate roll offset device, contains a roll-bending device and can use either a hydraulic cylinder, a screw jack, a wedge plate, or other means, as its actuator. Furthermore, the work roll offset device has its amount of actuation detected by a position detector.

[0108] Next, operational effects of roll offsetting are described below.

[0109] The present invention concerns reducing the diameter of the work rolls. It is generally known that reducing the diameter of a work roll makes the work roll easily deflect in a horizontal direction. As described previously herein, it is effective from a viewpoint of stable system operation to take any appropriate measures necessary to minimize such horizontal deflection.

[0110] Therefore, why and how the work roll deflects is first described below. Horizontal forces upon the work roll can be classified mainly into the following four types, and a resultant force thereof determines a direction and a magnitude of the deflection in the actual operation.

[0111]

(a) Difference in tension between the entry and exit sides of the work roll,
(b) drive tangential force for driving the intermediate roll and buck-up roll in case of the work roll drive,
(c) drive tangential force received from the intermediate roll in case of the intermediate roll drive, and
(d) component force of a rolling load generated by a relative deviation between axes of the work roll and the intermediate roll (referred to "offset" hereinafter).

[0112] Of the four types of forces, the forces (a), (b) and (c) are determined by the rolling conditions used in the actual operation, and the values of these forces can be perceived, but are difficult to intentionally change. The remaining force (d) is determined by the rolling load and the offset, and the rolling load is difficult to intentionally change as with forces (a) to (c), but the force (d) is the type of a horizontal force whose value can be changed if the offset can be changed.

[0113] In this way, as means for suppressing the deflection of the work roll in the horizontal direction as small as possible, it is known to provide the rolling mill with an offset device and make operable the horizontal force acting upon the work roll. More specifically, the horizontal force acting upon the work roll can be made nil in theory by deriving the value of the resultant of forces (a), (b), (c) and the rolling load beforehand and then determining a magnitude of the offset such that force (d) and the resultant of forces (a), (b), (c) become balanced with each other. During actual rolling, however, since it is difficult to derive accurate values of forces (a), (b), (c), and each value changes with time, it is beyond hope to make the horizontal force completely nil, so the offset is usually set to leave some degree of horizontal force, even in theoretical terms.

[0114] Causes that exert the horizontal force upon the work roll, and the beneficial effects of the offset have been described above. The offset device can use one of two major kinds of offsetting methods. Figs. 20A and 20B show the two kinds of offsetting methods. As discussed above, offsetting is to shift the center of the work roll and that of the intermediate roll in relative form. This can be implemented by, as shown in Fig. 20A, moving the work roll in the horizontal direction and thus providing the offset, or by as shown in Fig. 20B, moving the intermediate roll in the horizontal direction and thus providing the offset.

[0115] Next, comparisons between work roll offsetting and intermediate roll offsetting are described below. Both are the same in the purpose of reducing the horizontal deflection of the work roll. In actual operation, however, several differences are conceivable. First, work roll offsetting would cause the following inconveniences since it moves the work roll.

[0116]

(1) To set the offset before starting the rolling process, the upper and lower work rolls both need to be opened, and in addition, since the position of the work roll where it applies the rolling load to the steel strip before the work roll is offset will change between before and after the position change of the roll, and an indentation produced on the steel strip by the rolling load may hamper a smooth start of rolling.
(2) If the offset is changed during rolling, this might affect rolling quality since the work roll will be moved in the horizontal direction with the steel strip being rolled.

[0117] As opposed to this, intermediate roll drive has an advantage of causing no such inconveniences. That is to say:

(1) To set the offset before starting the rolling process, there is no need to open the upper or lower work roll, and in addition, even if the position of the intermediate roll is changed, a smooth start of rolling can be expected since the loading position of the work roll with respect to the steel strip will remain unchanged.
(2) Even if the offset is changed during rolling, this is not likely to affect rolling quality since the intermediate roll will be moved in the horizontal direction independently of the work roll that is rolling the steel strip.

[0118] The cold-rolling mill of the present invention can employ either work roll offsetting or intermediate roll offsetting, but in consideration of the comparison results as described above, intermediate roll offsetting is preferred.

[0119] Next, an embodiment in which the present invention employs intermediate roll drive is described below using Fig. 21. Fig. 21 is an external view that shows a drive system of an intermediate roll drive type, the external view having been taken from a side of the rolling mill.

[0120] Referring to Fig. 21, a cold-rolling mill 51A has substantially the same roll configuration as that of the embodiment shown in Figs. 1 to 3. The cold-rolling mill 51A in the present embodiment includes an intermediate roll drive unit 22 as a drive for the mill. The intermediate roll drive unit 22 includes a pair of upper and lower spindles 90, a gearbox (reduction gear) 94, a coupling 95, and an electric motor 96, with a driving force of the motor 96 being decremented or incremented at a predetermined rate in the gearbox 94 or causing no change in speed, and being transmitted to upper and lower paired intermediate rolls 3 while absorbing any vertical changes in position by means of the upper and lower paired spindles 90.

[0121] The upper and lower paired spindles 90 are, for example, universal joints described in Figs. 14A and 14B, and the spindles each including an intermediate shaft 91 and universal joint crosses 92, 93 provided at both ends of the intermediate shaft 91. The universal joints 90 are advantageous in that they are less expensive than gear spindles.

[0122] In addition, the cold-rolling mill 51A includes a roll offset device adapted to offset either one of the work rolls 2 and the intermediate rolls 3 relative to axes of the other rolls in the entry or exit side in a rolling direction. This roll offset device is preferably an intermediate roll offset device, as with that of the embodiment shown in Figs. 1 to 3. The roll offset device may however be a work roll offset device.

[0123] Other constituent elements of the cold-rolling mill 51A that are located on the stand side are substantially the same as those of the embodiment shown in Figs. 1 to 3.

[0124] The following describes embodiments of applying a cold-rolling mill of the present invention to a rolling system.

[0125] Fig. 22 is a diagram showing an embodiment of a tandem rolling system constructed using a cold-rolling mill of the present invention. The tandem rolling system includes a row of five stands of rolling mills 100a to 100e, all of which include one of the above-described cold-rolling mills of the present invention, for example the cold-rolling mill 51 shown in Fig. 14. With such a feature, high productivity as of the conventional tandem rolling system can be maintained and without increasing the stands, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed. The rolling mills 100a-100e may be of a configuration including at least one stand of cold-rolling mill of the present invention, and even in this case, the rolling system can implement rolling at high reduction ratios compared with those of a rolling system whose rolling mills are all prior-art ones.

[0126] Fig. 23 is a diagram showing an embodiment of a reversing rolling system constructed using a cold-rolling mill of the present invention. The reversing rolling system includes a single stand of reversing rolling mill 110, with coiling/uncoiling devices 111, 112 arranged at entry/exit sides of the rolling mill 110 and with deflector rolls 113, 114 further arranged between the coiling/uncoiling devices 111, 112. The rolling mill 110 includes one of the above-described cold-rolling mills of the present invention, for example the cold-rolling mill 51 shown in Fig. 14. With such a feature, high productivity as of the conventional reversing rolling system can be maintained and without increasing the number of reversing rolling passes, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed. The reversing rolling system may have two stands of rolling mills, and at least one of the two stands may be one of the cold-rolling mills of the present invention, for example the cold-rolling mill 51, whereby the rolling system will be able to implement rolling at high reduction ratios compared with those of a rolling system whose rolling mills are all prior-art ones.

[0127] Fig. 24 is a diagram showing an example of modifying a tandem rolling system using a cold-rolling mill of the present invention. The unmodified tandem rolling system includes a row of five stands of prior-art rolling mills 120a to 120e. In the shown example of modification, the rolling mill 120e of a final stand is changed into one of the cold-rolling mills of the present invention, for example the cold-rolling mill 51. This change may be performed by replacing one stand of rolling mill or partly modifying one stand of rolling mill. With such a feature, high productivity as of the tandem rolling system before modified can be maintained and without increasing the number of stands, rolling of a harder steel strip than the system before modified and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed. The number of the modified rolling mills may be two stands or more.

[0128] Fig. 25 is a diagram showing another example of modifying a tandem rolling system using a cold-rolling mill of the present invention. The unmodified tandem rolling system includes a row of five stands of prior-art rolling mills 120a to 120e. In the shown example of modification, one of the cold-rolling mills of the present invention, for example the cold-rolling mill 51, is additionally installed at an exit side of the row of rolling mills. With such a feature, high productivity as of the tandem rolling system before modified can be maintained and rolling of a harder steel strip than the system before modified and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed. The position at which the rolling mill of the present invention is additionally installed may instead be an entry side or both sides of the rolling mill array.

[0129] Although this modification is not shown, even the reversing rolling system shown in Fig. 23 can be modified

similarly to a tandem rolling system, by changing the reversing cold-rolling mill 110 into one of the cold-rolling mills of the present invention. With such a feature, by utilizing the existing system, rolling of a harder steel strip than ever and rolling of a steel strip of the same hardness as before at a higher reduction ratio can be performed.

Description of Reference Numbers

[0130]

1	Material to be rolled (Steel strip)
2	Work roll
3	Intermediate roll
3a	Chamfer
4	Buck-up roll
5	Housing
6, 8, 9	Bearing housings
10	Work roll bending device
11	Intermediate roll bending device
12	Shift block
14	Keeper plate
15	Hydraulic cylinder
16	Hydraulic cylinder
17	Project block
18	Stay
19	Intermediate roll offset device
20	Gear spindle
20A	Universal joint
21, 21A, 21B	Work roll drive units
22	Intermediate roll drive unit
23	Roll shifting device (Axial direction roll shifting device)
51, 51A	Cold rolling mills
52	Gearbox (reduction gear)
53	Coupling
53a, 53b	Flange portions

53c, 53d	Coupling half-bodies
54	Motor
61	Intermediate shaft
62, 63	Gear couplings
62A	Gear coupling
64, 65	Sleeves
64a, 65a	Internal teeth
66, 67	Hubs
66a, 67a	External teeth
68, 69	Recesses
71	Intermediate shaft
72, 73	Universal joint crosses
74, 75	Recesses
76	Cross joint
85, 86	Hydraulic torque limiters
87	Shear pin
90	Spindle
91	Intermediate shaft
92, 93	Universal joint crosses
94	Gearbox
95	Coupling
96	Motor

Claims

1. A cold-rolling mill for rolling a steel strip of minimum width not less than 600 mm and maximum width not less than 1,500 mm but not greater than 1,900 mm, the mill comprising:

a pair of upper and lower work rolls (2, 2);
a pair of upper and lower intermediate rolls (3, 3) supporting the work rolls, respectively;
a pair of upper and lower buck-up rolls (4, 4) supporting the intermediate rolls, respectively;
an axial direction roll shifting device (23) for each of the intermediate rolls; and
bending devices (10, 11) for each of the work rolls and the intermediate rolls;
wherein the work rolls each have a diameter not less than 300 mm but not greater than 400 mm,
characterized in that the intermediate rolls each have a diameter not less than 560 mm but not greater than 690 mm.

2. The cold-rolling mill according to claim 1, wherein:

a work roll drive unit (21) for rotationally driving the work rolls (2, 2) is provided as a drive unit for the rolling mill.

3. The cold-rolling mill according to claim 2, wherein:

the work roll drive unit (21) includes gear spindles (20, 20) adapted to transmit a driving force of an electric motor (54) to each of the work rolls (22).

4. The cold-rolling mill according to claim 2 or 3, wherein:

the work roll drive unit (21A; 21B) includes an overload preventive device (85; 86; 87) adapted to prevent damage to the spindles (20, 20).

5. The cold-rolling mill according to any one of claims 1 to 4, further comprising:

a roll offset device (19) adapted to offset either one of the work rolls (2, 2) and the intermediate rolls (3, 3) relative to axes of the other rolls to an entry or exit side in a rolling direction.

6. The cold-rolling mill according to claim 1, wherein:

an intermediate roll drive unit (22) for rotationally driving the intermediate rolls (3, 3) is provided as a drive unit for the rolling mill.

7. The cold-rolling mill according to claim 6, wherein:

the intermediate roll drive unit (22) includes universal joints (90, 90) adapted to transmit a driving force of an electric motor (96) to each of the intermediate rolls (3, 3).

8. The cold-rolling mill according to claim 6 or 7, further comprising:

a roll offset device (19) adapted to offset either one of the work rolls (2, 2) and the intermediates roll (3, 3) relative to axes of the other rolls to an entry or exit side in a rolling direction.

9. A tandem rolling system comprises a rolling mill line having plural stands of rolling mills (100a to 100e), wherein:

the plural stands of rolling mills include at least one stand of the cold-rolling mill (51) according to any one of claims 1 to 8.

10. A reversing rolling system comprising at least one reversing rolling mill (110), wherein:

the reversing rolling mill includes at least one cold-rolling mill (51) according to any one of claims 1 to 8.

11. A modification method of a rolling system having one or plural stands of rolling mills (110; 120a to 120e), the method comprising:

modifying at least one stand of the rolling mill into the cold-rolling mill (51) according to any one of claims 1 to 8.

12. An operating method of a cold-rolling mill, the method comprising:

rolling the steel strip (1) at a reduction ratio higher than 12% by using the cold-rolling mill according to any one of claims 1 to 8.

Patentansprüche

1. Kaltwalzwerk zum Walzen eines Stahlbandes einer minimalen Breite von nicht weniger als 600 mm und einer maximalen Breite von nicht weniger als 1.500 mm, aber nicht größer als 1.900 mm, wobei das Walzwerk aufweist:

ein Paar oberer und unterer Arbeitswalzen (2, 2);
ein Paar oberer und unterer Zwischenwalzen (3, 3), die die Arbeitswalzen jeweils tragen;
ein Paar oberer und unterer Stützwalzen (4, 4), die jeweils die Zwischenwalzen tragen;
eine Vorrichtung (23) zum Verschieben einer Walze in Axialrichtung für jede der Zwischenwalzen; und
Biegeeinrichtungen (10, 11) für jede der Arbeitswalzen und der Zwischenwalzen;
wobei die Arbeitswalzen jeweils einen Durchmesser aufweisen von nicht weniger als 300 mm, aber nicht mehr als 400 mm, **dadurch gekennzeichnet, dass** die Zwischenwalzen jeweils einen Durchmesser von nicht weniger als 560 mm, aber nicht mehr als 690 mm aufweisen.

2. Kaltwalzwerk nach Anspruch 1, wobei
eine Arbeitswalzenantriebseinheit (21) für den Drehantrieb der Arbeitswalzen (2, 2) als eine Antriebseinheit für das Walzwerk vorgesehen ist.

3. Kaltwalzwerk nach Anspruch 2, wobei
die Arbeitswalzenantriebseinheit (21) Gewindespindeln (20, 20) aufweist, die ausgebildet sind, um eine Antriebskraft eines Elektromotors (54) zu jeder der Arbeitswalzen (22) zu übertragen.

4. Kaltwalzwerk nach Anspruch 2 oder 3, wobei
die Arbeitswalzenantriebseinheit (21A; 21B) eine Überlastungsschutzvorrichtung (85, 86, 87) aufweist, die ausgebildet ist, um eine Beschädigung der Spindeln (20, 20) zu verhindern.

5. Kaltwalzwerk nach einem der Ansprüche 1 bis 4, das ferner aufweist:

eine Walzenversatzvorrichtung (19), die dazu ausgebildet ist, entweder eine der Arbeitswalzen (2, 2) oder eine der Zwischenwalzen (3, 3) relativ zu Achsen der anderen Walzen auf eine Eingangs- oder Ausgangsseite in einer Walzrichtung zu versetzen.

6. Kaltwalzwerk nach Anspruch 1, wobei
eine Zwischenwalzenantriebseinheit (22) für den Drehantrieb der Zwischenwalzen (3, 3) als eine Antriebseinheit des Walzwerks vorgesehen ist.

7. Kaltwalzwerk nach Anspruch 6, wobei
die Zwischenwalzenantriebseinheit (22) Kardangelenke (90, 90) aufweist, die ausgebildet sind, um eine Antriebskraft eines Elektromotors (96) zu jeder der Zwischenwalzen (3, 3) zu übertragen.

8. Kaltwalzwerk nach Anspruch 6 oder 7, das ferner aufweist:

eine Walzenversatzvorrichtung (19), die ausgebildet ist, um entweder eine der Arbeitswalzen (2, 2) oder eine der Zwischenwalzen (3, 3) relativ zu Achsen der anderen Walzen auf eine Eingangs- oder Ausgangsseite in Walzrichtung zu versetzen.

9. Tandemwalzsystem mit einer Walzstraße mit mehreren Walzgerüsten (100a bis 100e), wobei
die mehreren Walzwerkgerüste mindestens ein Kaltwalzwerkgerüst (51) nach einem der Ansprüche 1 bis 8 umfassen.

10. Reversierwalzsystem mit mindestens einem Reversierwalzwerk (110), wobei
das Reversierwalzwerk mindestens ein Kaltwalzwerk (51) nach einem der Ansprüche 1 bis 8 aufweist.

11. Verfahren zum Modifizieren eines Walzsystems mit einem oder mehreren Walzwerkgerüsten (110; 120a bis 120e), wobei das Verfahren aufweist:

Modifizierung mindestens eines Gerüsts des Walzwerks in das Kaltwalzwerk (51) gemäß einem der Ansprüche 1 bis 8.

12. Verfahren zum Betreiben eines Kaltwalzwerks, wobei das Verfahren aufweist:

Walzen des Stahlbands (1) mit einem Reduktionsverhältnis von mehr als 12% unter Verwendung des Kaltwalzwerks nach einem der Ansprüche 1 bis 8.

Revendications

1. Laminoir à froid pour laminer une bande d'acier d'une largeur minimum non inférieure à 600 mm et d'une largeur maximum non inférieure à 1 500 mm mais non supérieure à 1 900 mm, le laminoir comprenant :

   une paire de cylindres (2, 2) de travail supérieur et inférieur ;
   une paire de cylindres (3, 3) intermédiaires supérieur et inférieur supportant les cylindres de travail, respectivement ;
   une paire de cylindres (4, 4) d'appui supérieur et inférieur supportant les cylindres intermédiaires, respectivement ;
   un dispositif (23) de déplacement de cylindre dans le sens axial pour chacun des cylindres intermédiaires ; et des dispositifs (10, 11) de courbure pour chacun des cylindres de travail et des cylindres intermédiaires ;
   dans lequel les cylindres de travail ont chacun un diamètre non inférieur à 300 mm mais non supérieur à 400 mm, **caractérisé en ce que** les cylindres intermédiaires ont chacun un diamètre non inférieur à 560 mm mais non supérieur à 690 mm.

2. Laminoir à froid selon la revendication 1, dans lequel :

   une unité (21) d'entraînement de cylindres de travail pour entraîner en rotation les cylindres (2, 2) de travail est prévue comme une unité d'entraînement pour le laminoir.

3. Laminoir à froid selon la revendication 2, dans lequel :

   l'unité (21) d'entraînement de cylindres de travail inclut des arbres (20, 20) à engrenage adaptés à transmettre une force d'entraînement d'un moteur (54) électrique à chacun des cylindres (2, 2) de travail.

4. Laminoir à froid selon la revendication 2 ou 3, dans lequel :

   l'unité (21A ; 21B) d'entraînement de cylindres de travail inclut un dispositif (85 ; 86 ; 87) de prévention de surcharge adapté à prévenir un endommagement des arbres (20, 20).

5. Laminoir à froid selon l'une quelconque des revendications 1 à 4, comprenant en outre :

   un dispositif (19) de décalage de cylindre adapté à décaler l'un ou l'autre des cylindres (2, 2) de travail et des cylindres (3, 3) intermédiaires par rapport à des axes des autres cylindres vers un côté d'entrée ou de sortie dans un sens de laminage.

6. Laminoir à froid selon la revendication 1, dans lequel :

   une unité (22) d'entraînement de cylindres intermédiaires pour entraîner en rotation les cylindres (3, 3) intermédiaires est prévue comme une unité d'entraînement pour le laminoir.

7. Laminoir à froid selon la revendication 6, dans lequel :

   l'unité (22) d'entraînement de cylindres intermédiaires inclut des articulations (90, 90) universelles adaptées à transmettre une force d'entraînement d'un moteur (96) électrique à chacun des cylindres (3, 3) intermédiaires.

8. Laminoir à froid selon la revendication 6 ou 7, comprenant en outre :

   un dispositif (19) de décalage de cylindre adapté à décaler l'un ou l'autre des cylindres (2, 2) de travail et des cylindres (3, 3) intermédiaires par rapport à des axes des autres cylindres vers un côté d'entrée ou de sortie dans un sens de laminage.

9. Système de laminage en tandem comprenant une ligne de laminoirs ayant plusieurs postes de laminoirs (100a à 100e), dans lequel :

   les plusieurs postes de laminoirs incluent au moins un poste du laminoir (51) à froid selon l'une quelconque des revendications 1 à 8.

10. Système de laminage réversible comprenant au moins un laminoir (110) réversible, dans lequel :

le laminoir réversible inclut au moins un laminoir (51) à froid selon l'une quelconque des revendications 1 à 8.

11. Procédé de modification d'un système de laminage ayant un ou plusieurs poste(s) de laminoirs (110 ; 120a à 120e), le procédé comprenant :

la modification d'au moins un poste du laminoir en le laminoir (51) à froid selon l'une quelconque des revendications 1 à 8.

12. Procédé de fonctionnement d'un laminoir à froid, le procédé comprenant :

le laminage d'une bande (1) d'acier à un taux de réduction supérieur à 12% en utilisant le laminoir à froid selon l'une quelconque des revendications 1 à 8.

FIG. 1

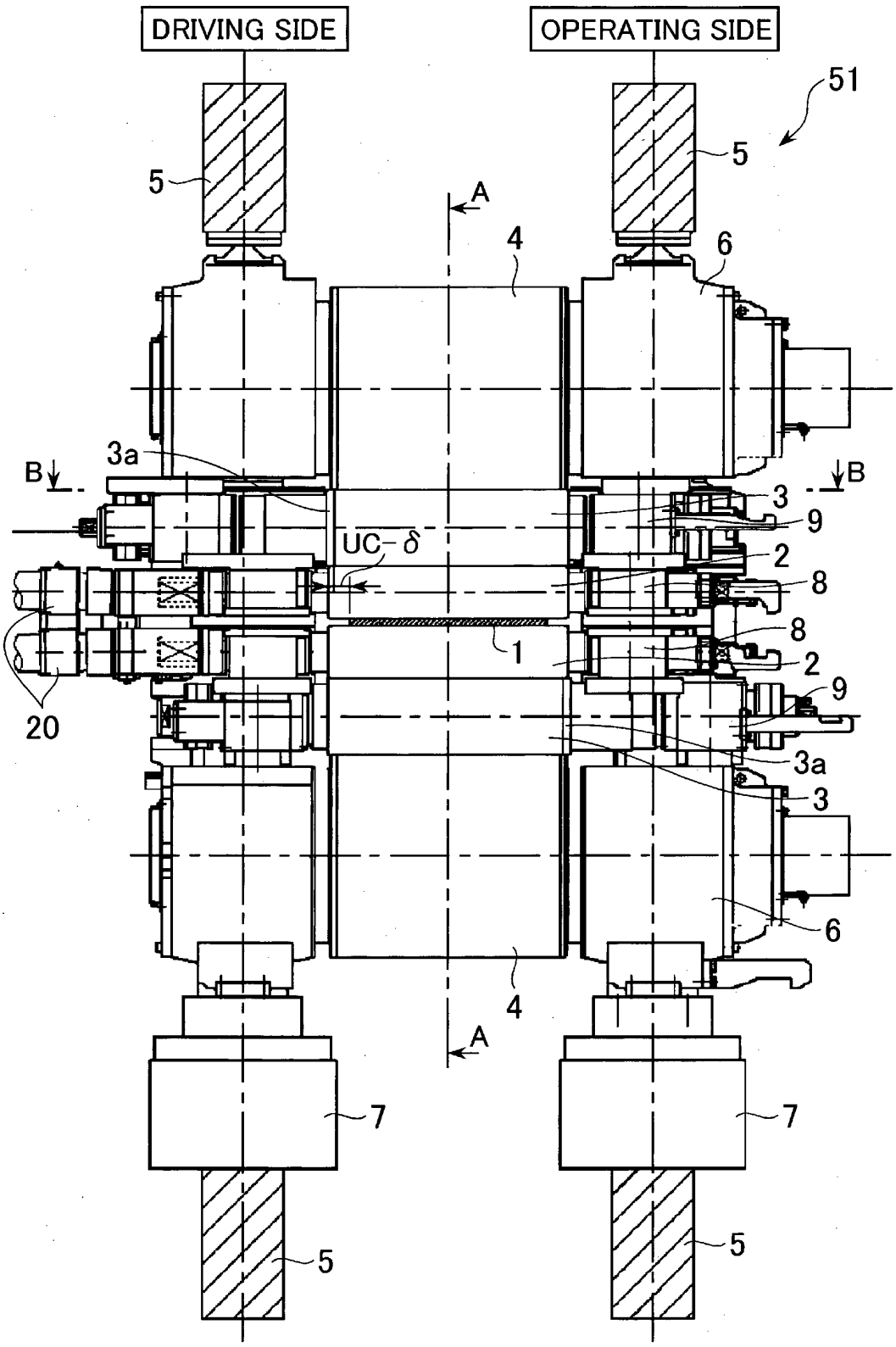

DRIVING SIDE
OPERATING SIDE
51
5
5
A
4
6
B
3a
B
3
9
UC
δ
2
8
8
1
2
9
20
3a
3
6
4
A
7
7
5
5

FIG. 2

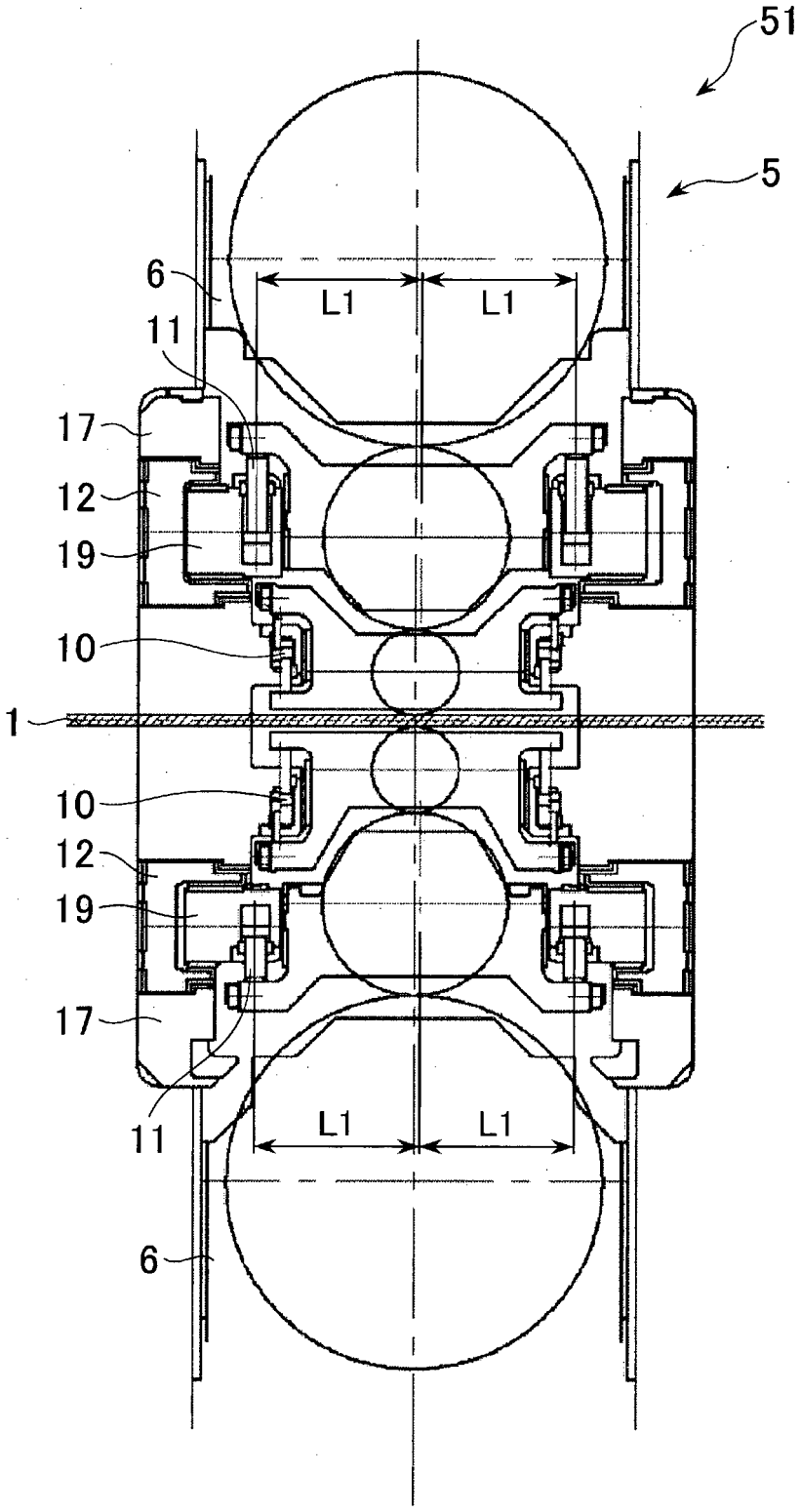


FIG. 3

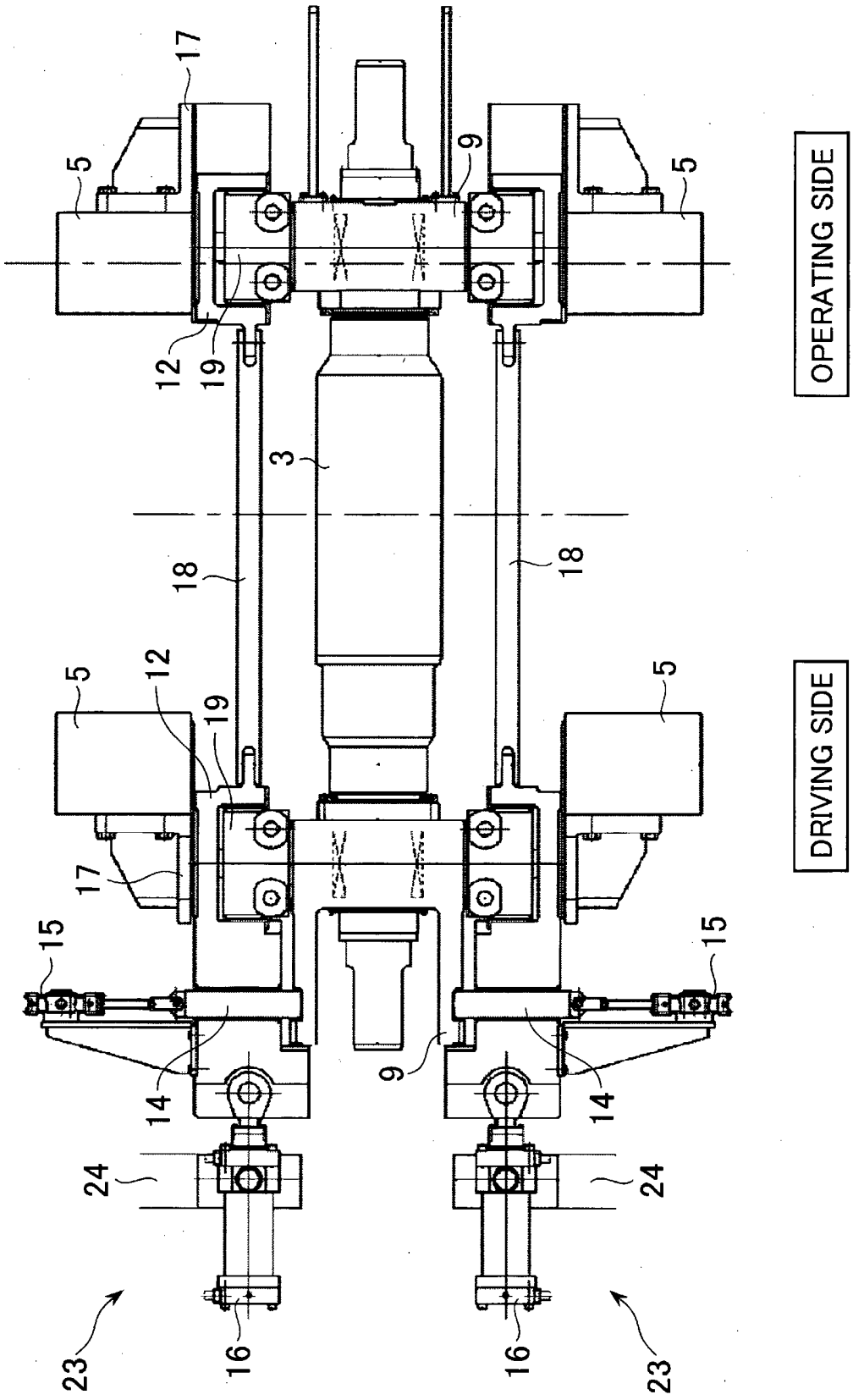

OPERATING SIDE
DRIVING SIDE
17
5
9
5
12
19
3
18
18
5
12
19
5
17
15
15
14
9
14
24
24
23
16
16
23

FIG.4

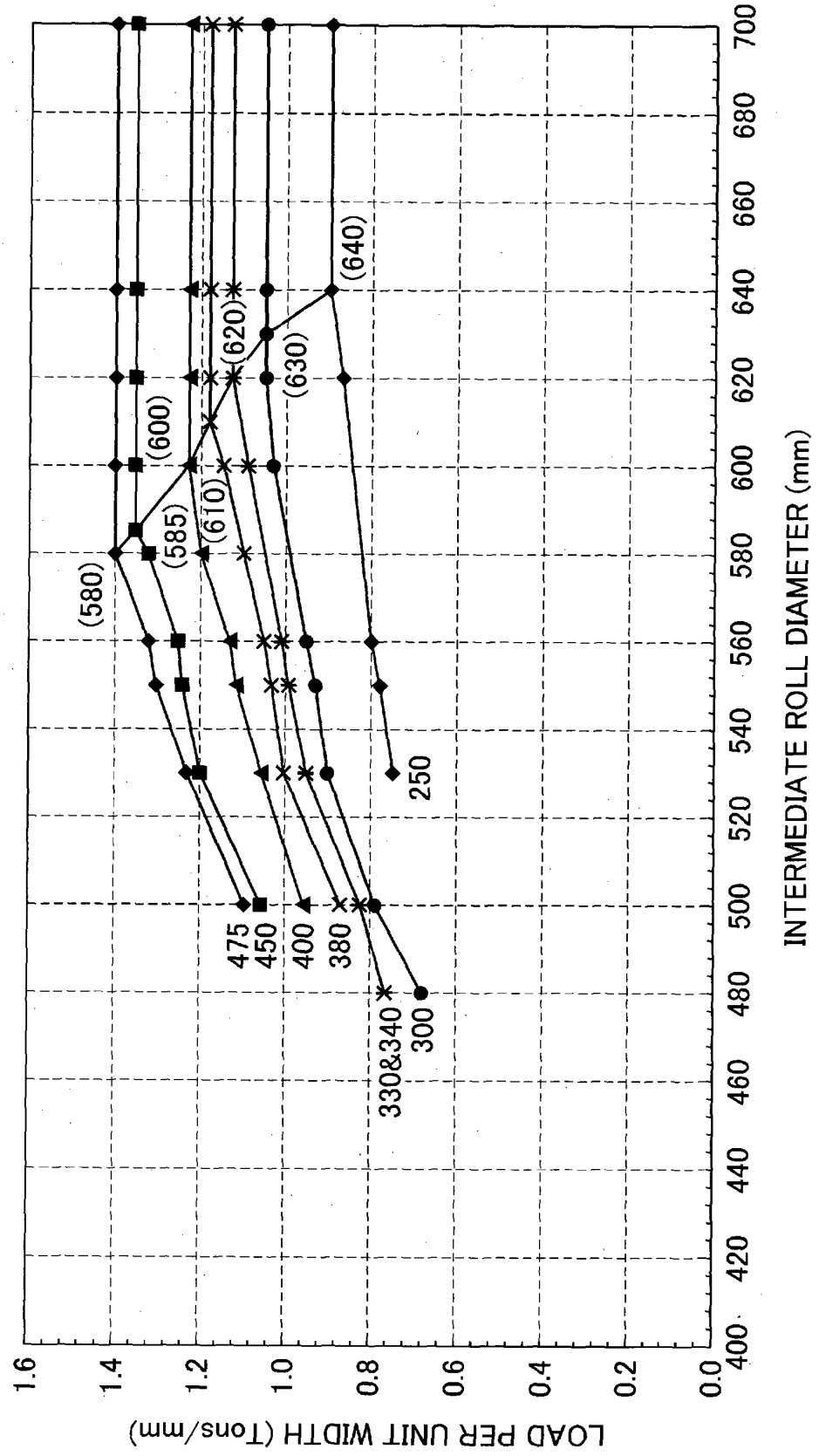

LOAD PER UNIT WIDTH (Tons/mm)
INTERMEDIATE ROLL DIAMETER (mm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
(580)
(585)
(600)
(610)
(620)
(630)
(640)
475
450
400
380
330&340
300
250

FIG.5

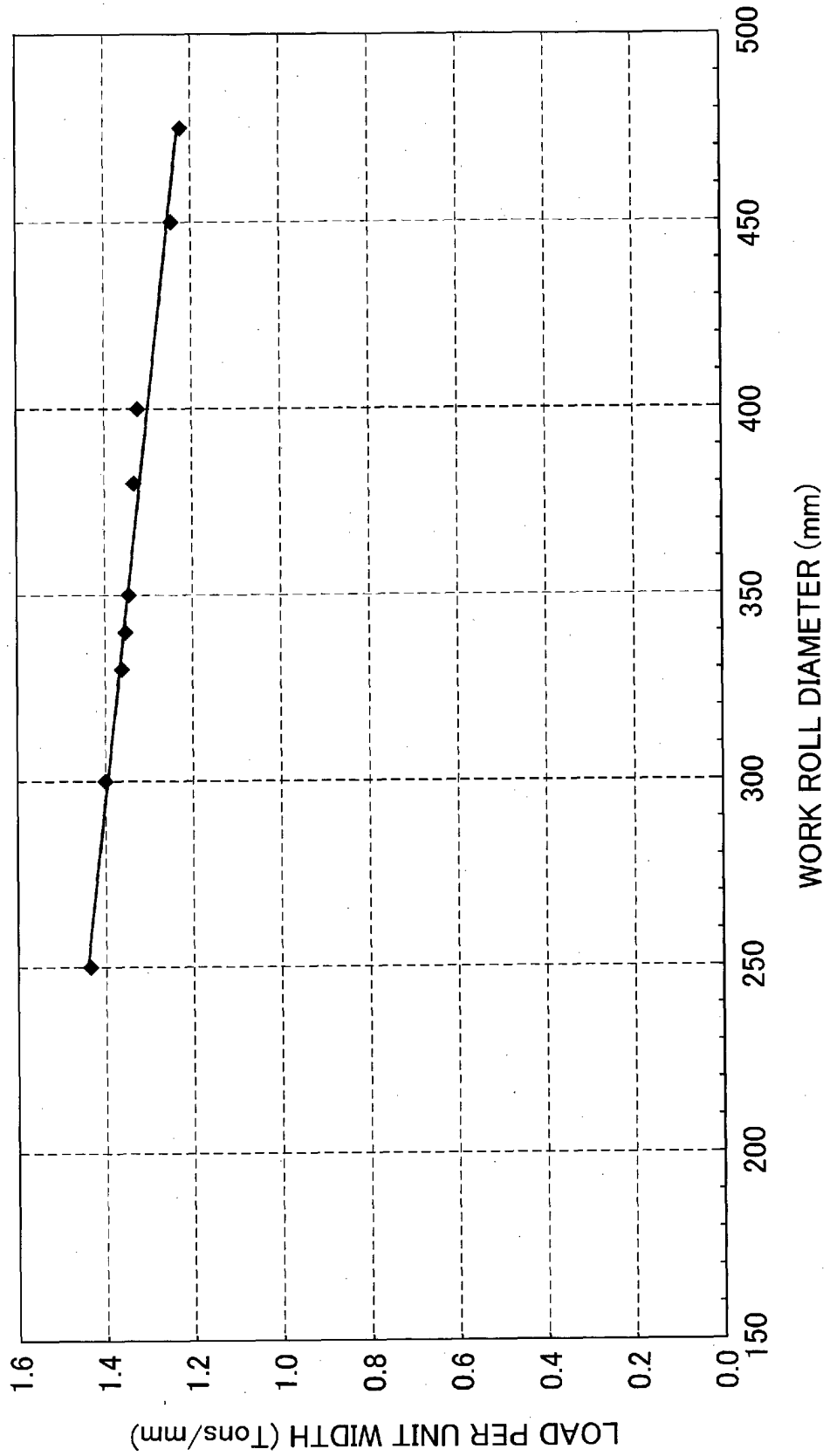

LOAD PER UNIT WIDTH (Tons/mm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
150
200
250
300
350
400
450
500
WORK ROLL DIAMETER (mm)

FIG.6

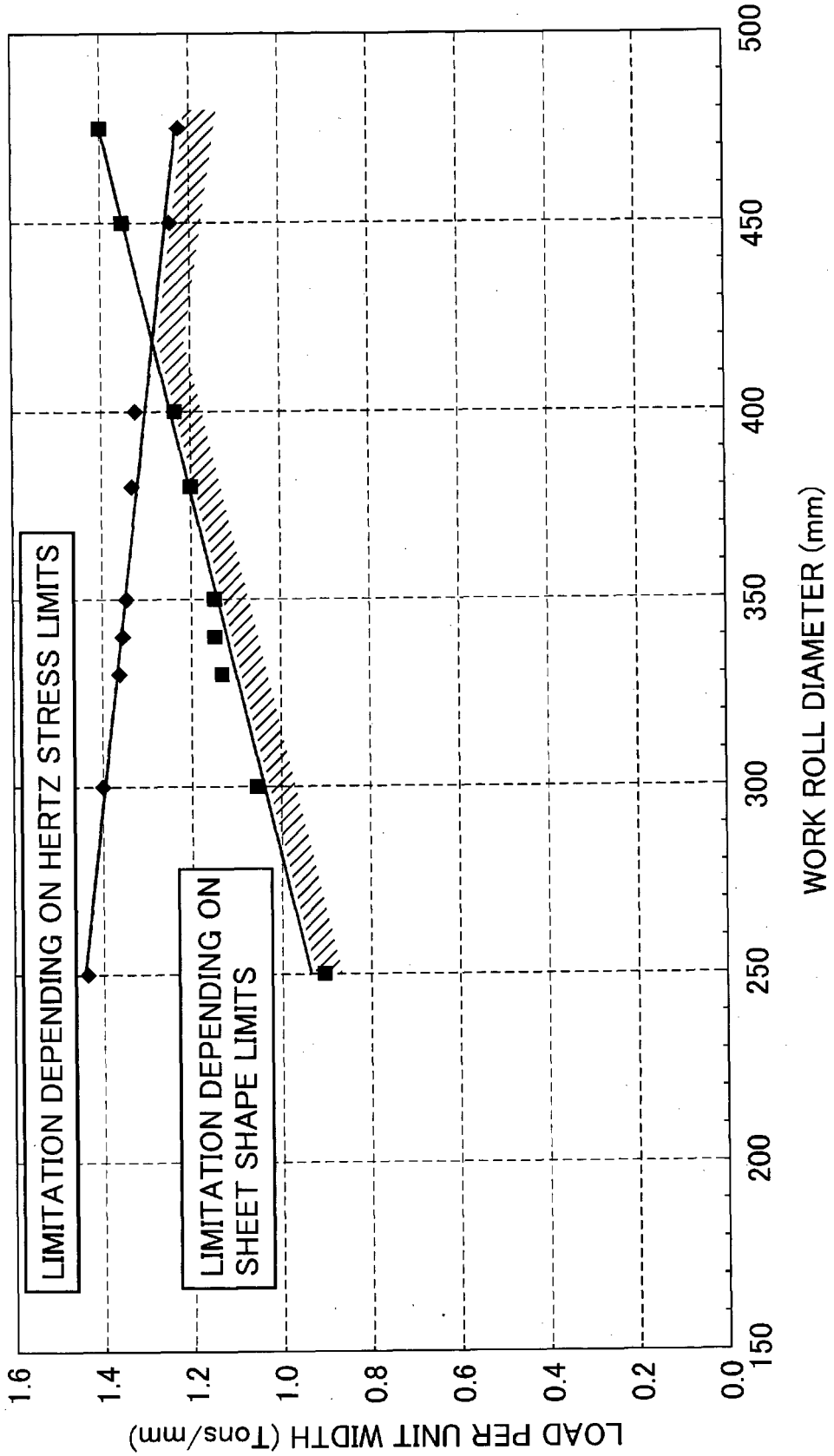

LIMITATION DEPENDING ON HERTZ STRESS LIMITS
LIMITATION DEPENDING ON SHEET SHAPE LIMITS
LOAD PER UNIT WIDTH (Tons/mm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
WORK ROLL DIAMETER (mm)
150
200
250
300
350
400
450
500

FIG.7

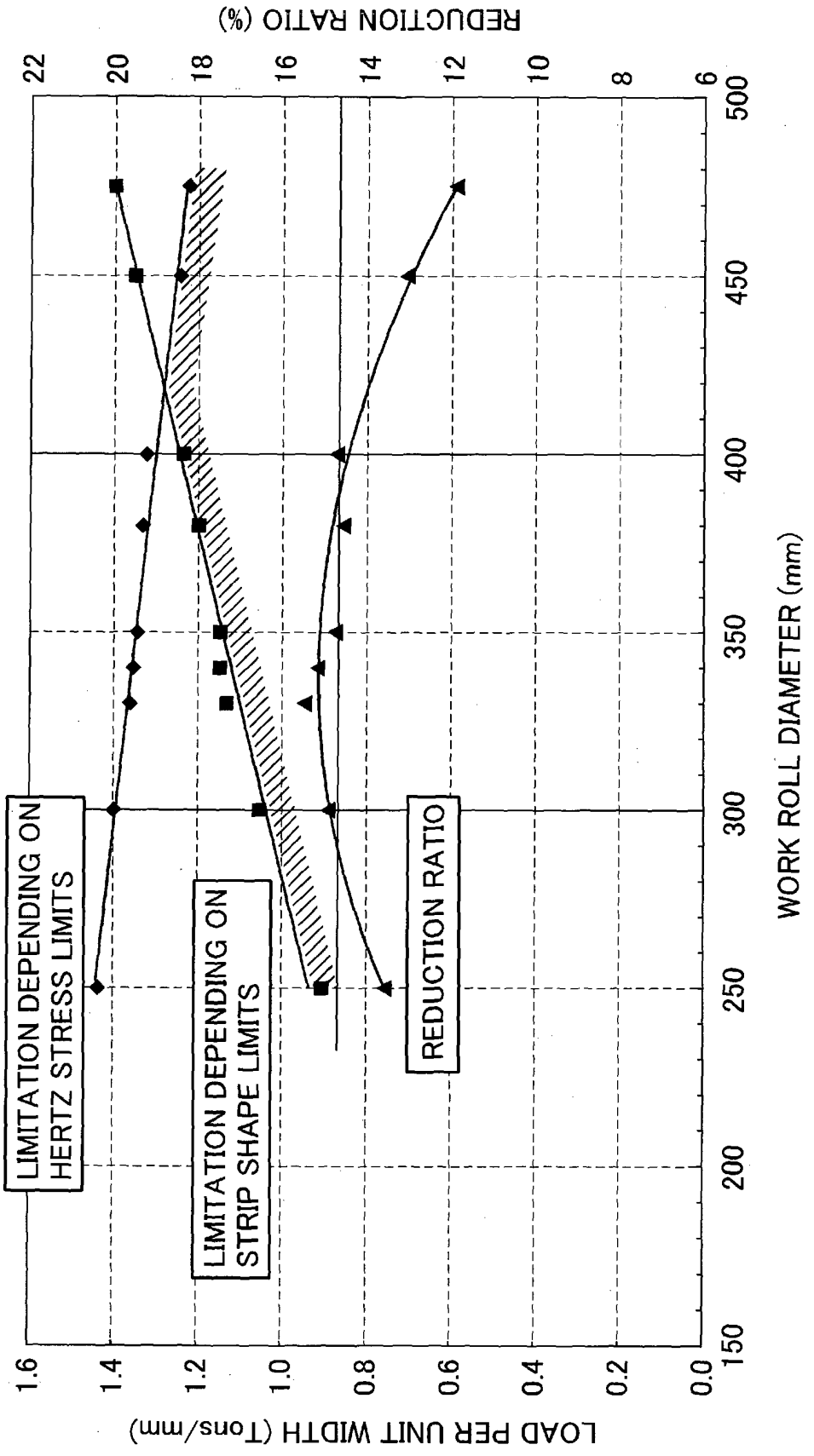

REDUCTION RATIO (%)
22
20
18
16
14
12
10
8
6
LOAD PER UNIT WIDTH (Tons/mm)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
WORK ROLL DIAMETER (mm)
150
200
250
300
350
400
450
500
LIMITATION DEPENDING ON HERTZ STRESS LIMITS
LIMITATION DEPENDING ON STRIP SHAPE LIMITS
REDUCTION RATIO

FIG.8

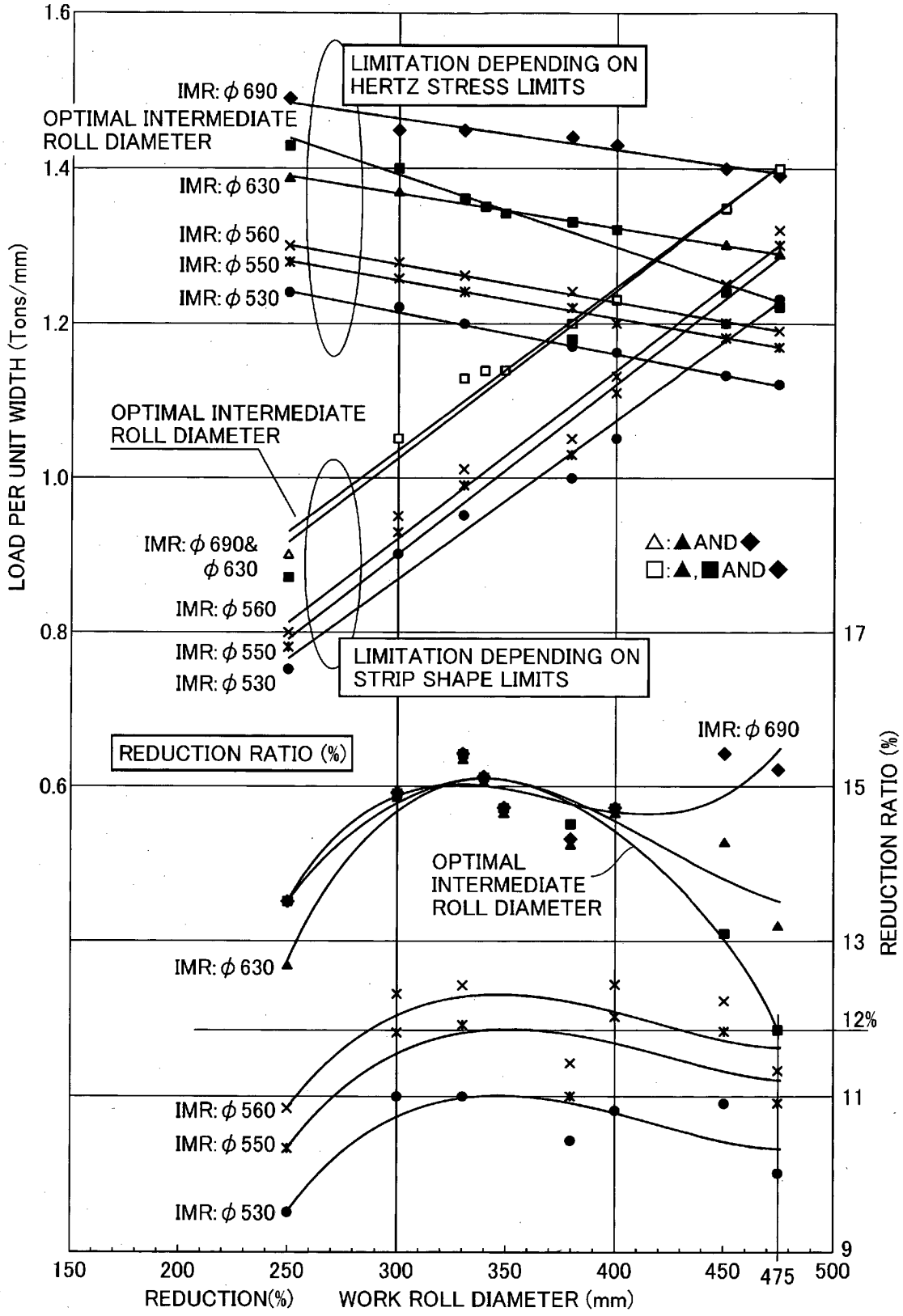

LIMITATION DEPENDING ON HERTZ STRESS LIMITS
IMR: φ690
OPTIMAL INTERMEDIATE ROLL DIAMETER
IMR: φ630
IMR: φ560
IMR: φ550
IMR: φ530
OPTIMAL INTERMEDIATE ROLL DIAMETER
IMR: φ690& φ630
IMR: φ560
IMR: φ550
IMR: φ530
△:▲AND◆
□:▲,■AND◆
LIMITATION DEPENDING ON STRIP SHAPE LIMITS
REDUCTION RATIO (%)
IMR: φ690
OPTIMAL INTERMEDIATE ROLL DIAMETER
IMR: φ630
IMR: φ560
IMR: φ550
IMR: φ530
12%
LOAD PER UNIT WIDTH (Tons/mm)
REDUCTION RATIO (%)
1.6
1.4
1.2
1.0
0.8
0.6
17
15
13
11
9
150
200
250
300
350
400
450
475
500
REDUCTION(%)
WORK ROLL DIAMETER (mm)

FIG.9

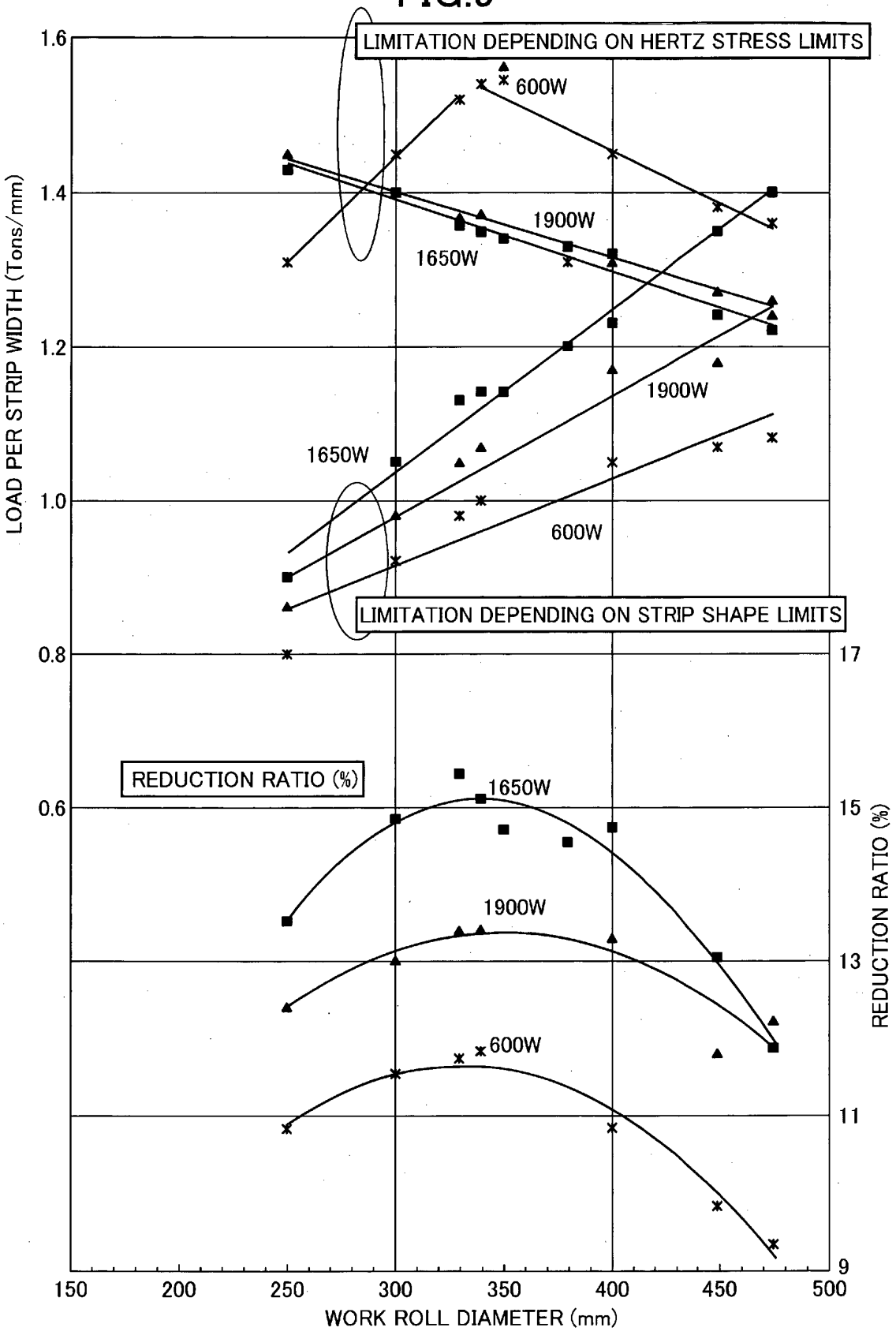

LIMITATION DEPENDING ON HERTZ STRESS LIMITS
600W
1900W
1650W
1900W
1650W
600W
LIMITATION DEPENDING ON STRIP SHAPE LIMITS
REDUCTION RATIO (%)
1650W
1900W
600W
LOAD PER STRIP WIDTH (Tons/mm)
REDUCTION RATIO (%)
WORK ROLL DIAMETER (mm)
1.6
1.4
1.2
1.0
0.8
0.6
17
15
13
11
9
150
200
250
300
350
400
450
500

FIG.10

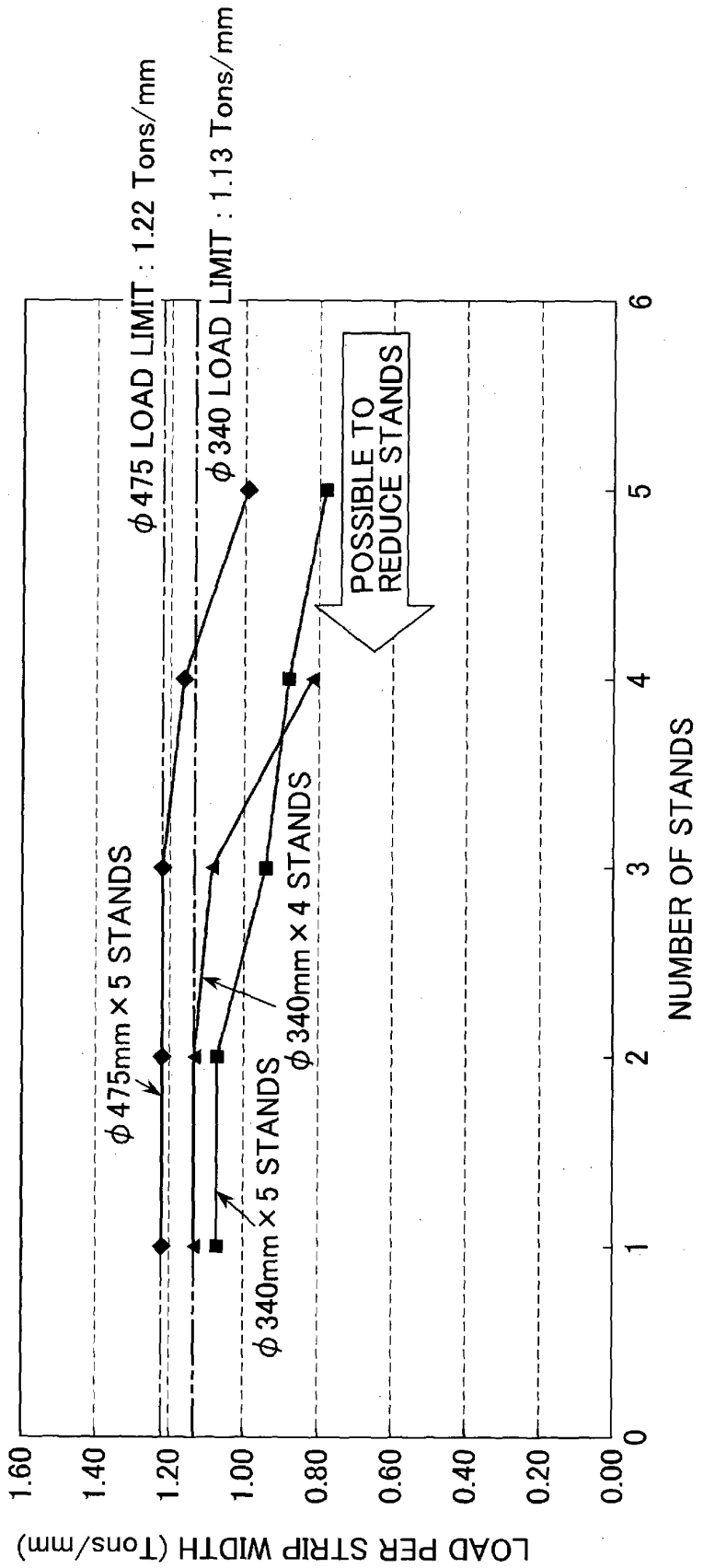

LOAD PER STRIP WIDTH (Tons/mm)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
1
2
3
4
5
6
NUMBER OF STANDS
φ475 LOAD LIMIT : 1.22 Tons/mm
φ340 LOAD LIMIT : 1.13 Tons/mm
POSSIBLE TO REDUCE STANDS
φ475mm × 5 STANDS
φ340mm × 5 STANDS
φ340mm × 4 STANDS

FIG.11

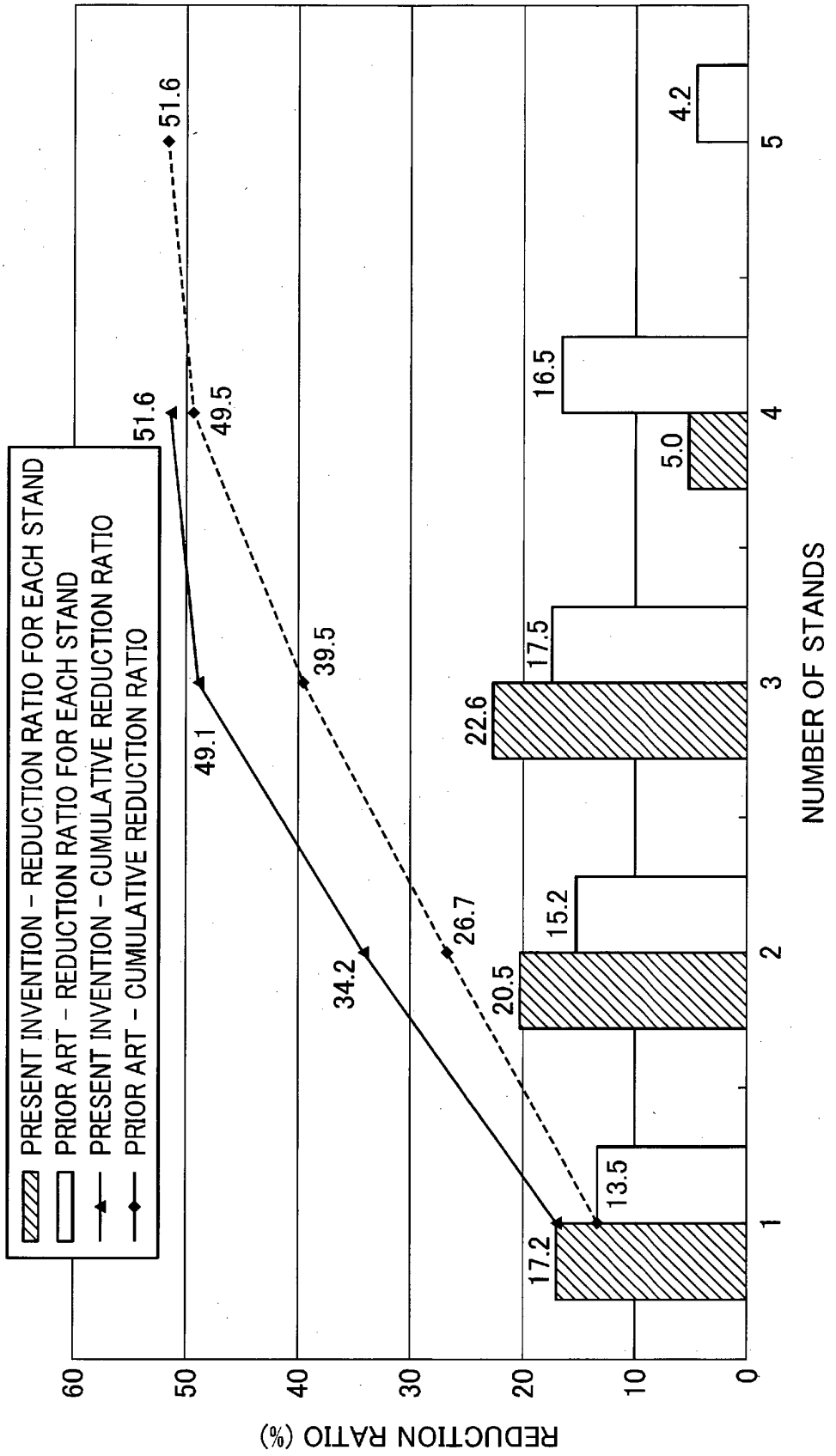

PRESENT INVENTION – REDUCTION RATIO FOR EACH STAND
PRIOR ART – REDUCTION RATIO FOR EACH STAND
PRESENT INVENTION – CUMULATIVE REDUCTION RATIO
PRIOR ART – CUMULATIVE REDUCTION RATIO
REDUCTION RATIO (%)
NUMBER OF STANDS
0
10
20
30
40
50
60
1
2
3
4
5
17.2
13.5
20.5
15.2
22.6
17.5
5.0
16.5
4.2
51.6
49.5
39.5
26.7
51.6
49.1
34.2

FIG.12

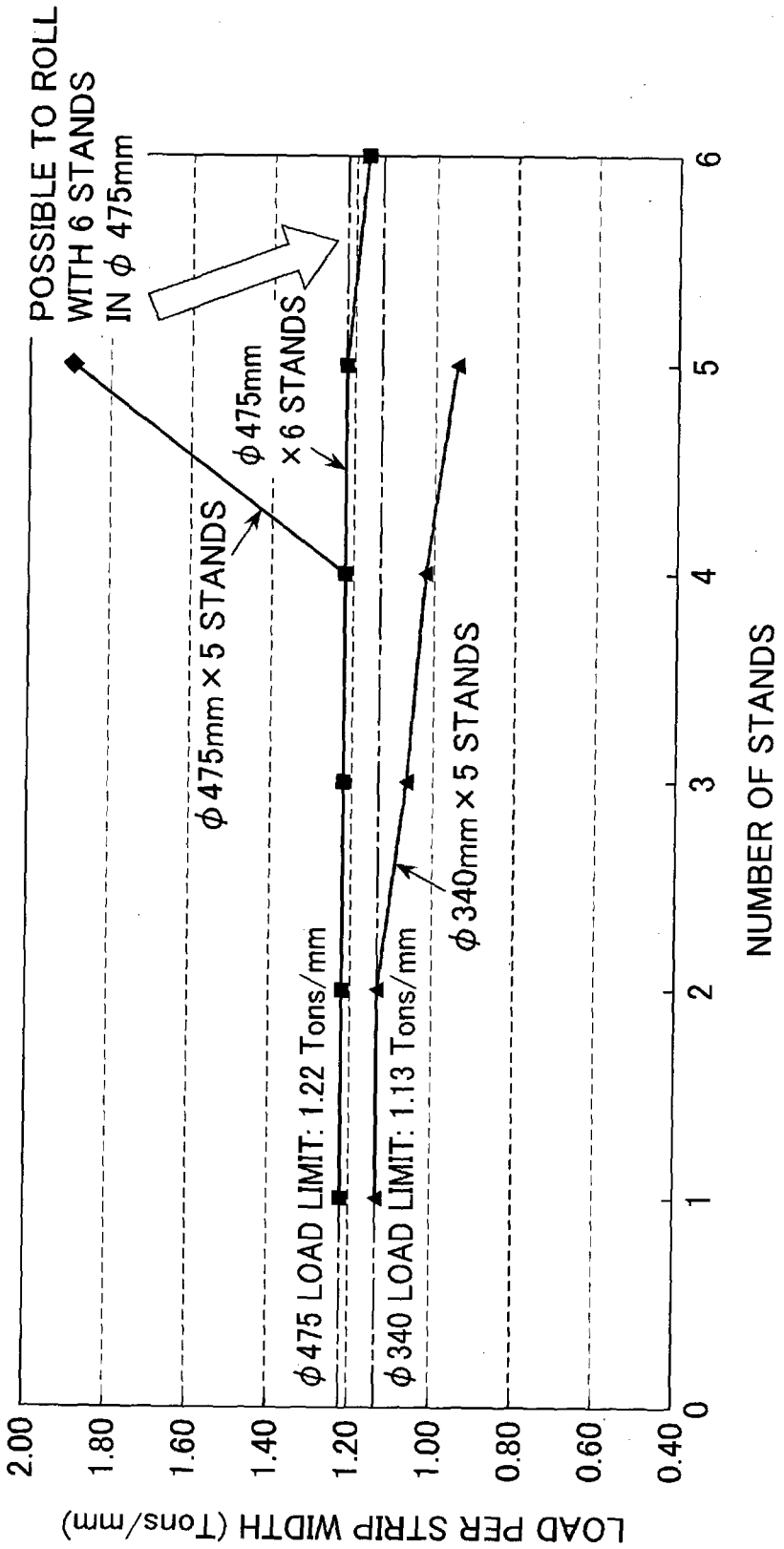

POSSIBLE TO ROLL
WITH 6 STANDS
IN φ 475mm
φ475mm × 5 STANDS
φ475mm
× 6 STANDS
φ475 LOAD LIMIT: 1.22 Tons/mm
φ340 LOAD LIMIT: 1.13 Tons/mm
φ340mm × 5 STANDS
LOAD PER STRIP WIDTH (Tons/mm)
NUMBER OF STANDS
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0
1
2
3
4
5
6

FIG.13

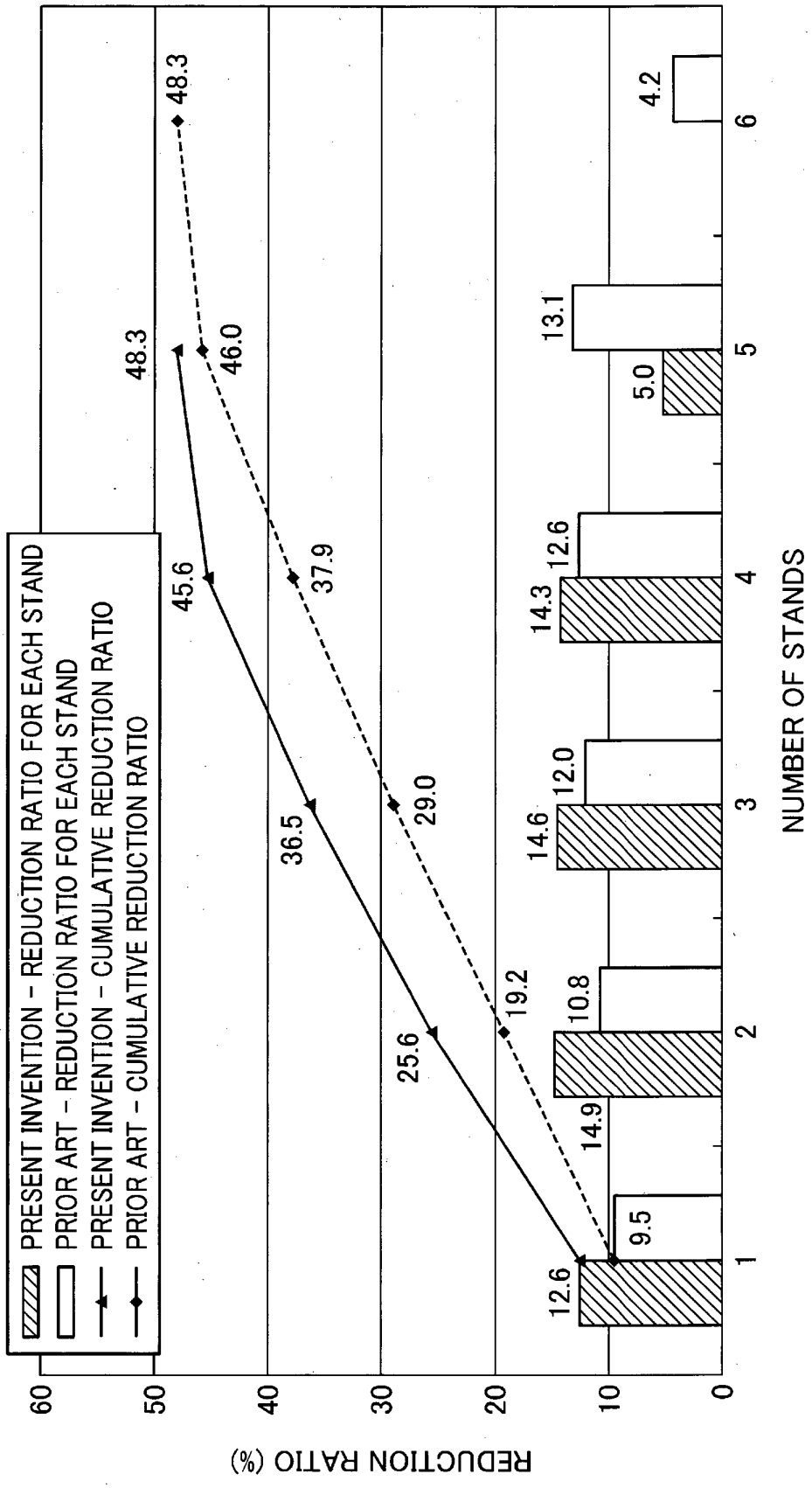

PRESENT INVENTION - REDUCTION RATIO FOR EACH STAND
PRIOR ART - REDUCTION RATIO FOR EACH STAND
PRESENT INVENTION - CUMULATIVE REDUCTION RATIO
PRIOR ART - CUMULATIVE REDUCTION RATIO
REDUCTION RATIO (%)
NUMBER OF STANDS
0
10
20
30
40
50
60
1
2
3
4
5
6
12.6
9.5
14.9
10.8
14.6
12.0
14.3
12.6
5.0
13.1
4.2
48.3
46.0
37.9
29.0
19.2
48.3
45.6
36.5
25.6

FIG.14

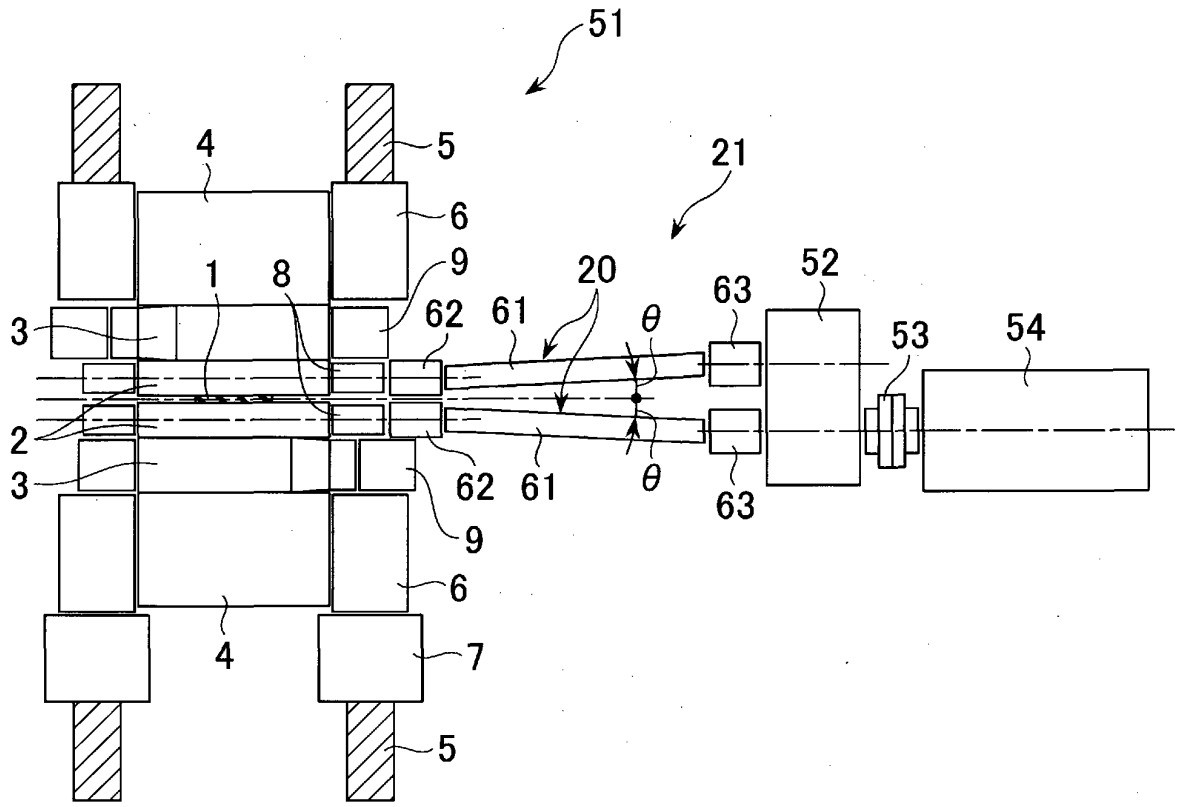


FIG.15

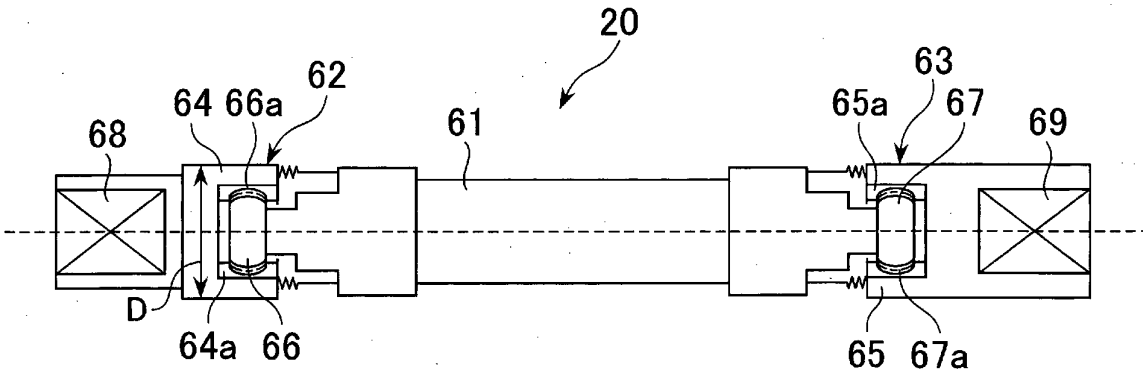


FIG.16A

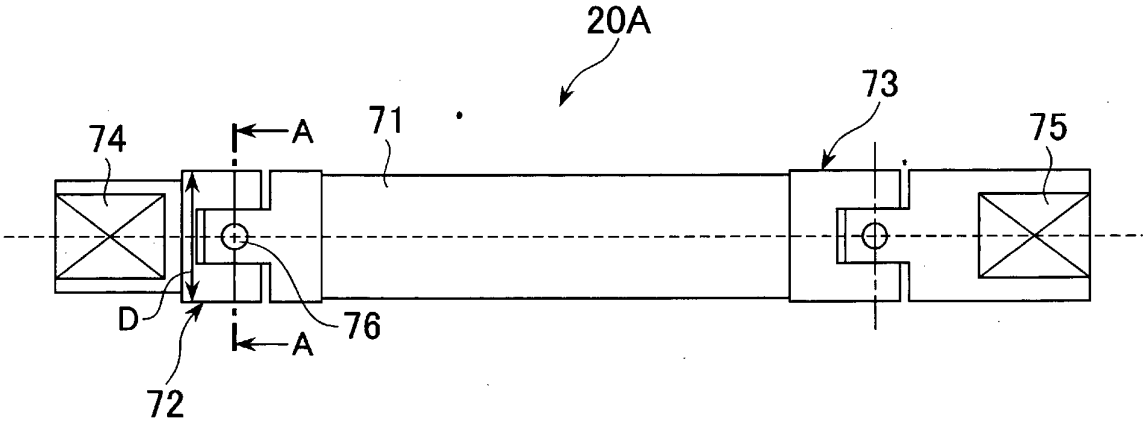


FIG.16B

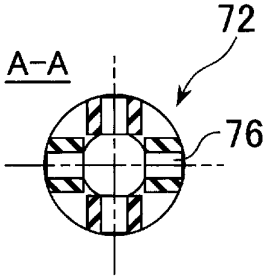


FIG.17

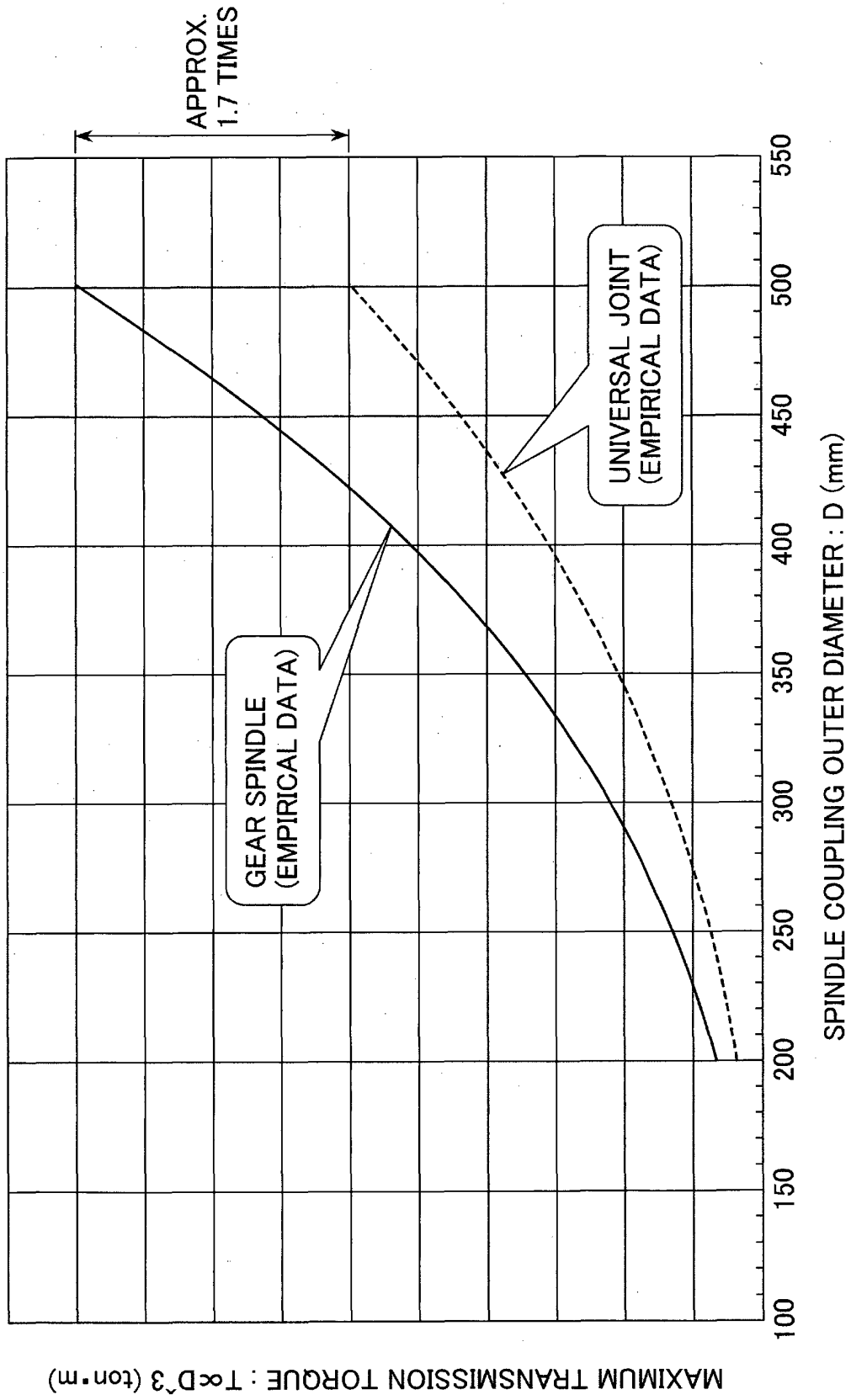

APPROX.
1.7 TIMES
GEAR SPINDLE
(EMPIRICAL DATA)
UNIVERSAL JOINT
(EMPIRICAL DATA)
MAXIMUM TRANSMISSION TORQUE : T∝D^3 (ton·m)
SPINDLE COUPLING OUTER DIAMETER : D (mm)
100
150
200
250
300
350
400
450
500
550

FIG.18A

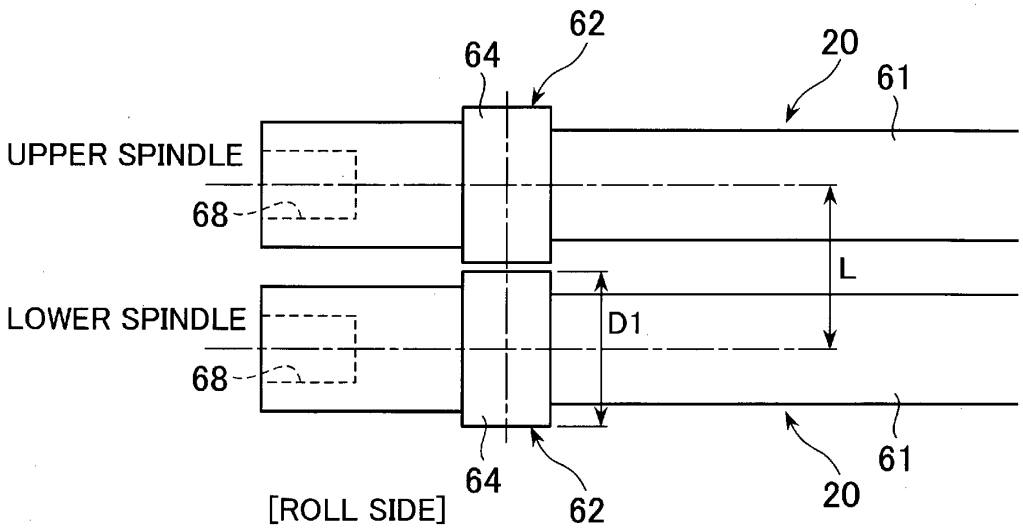


FIG.18B

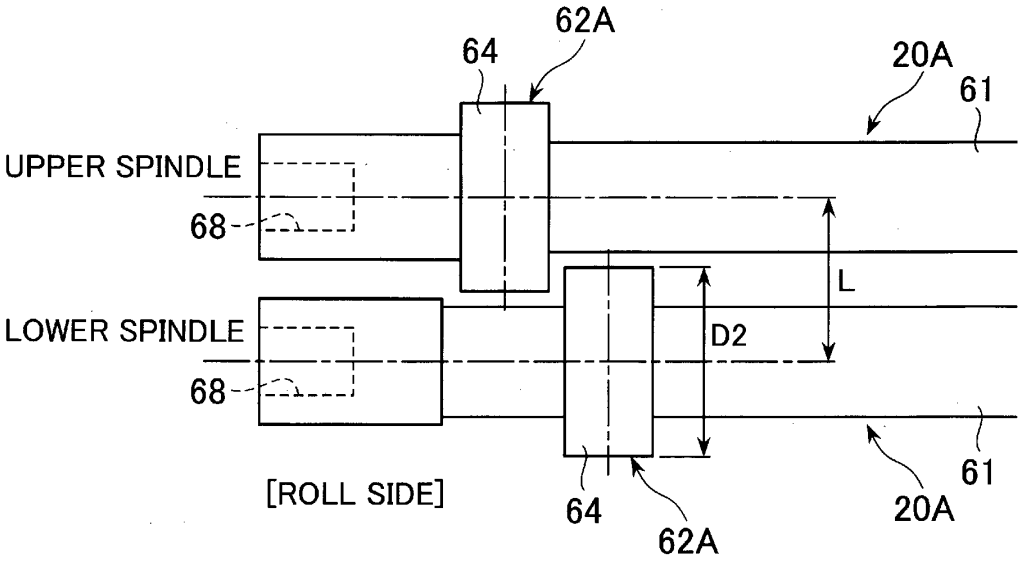


FIG.19A

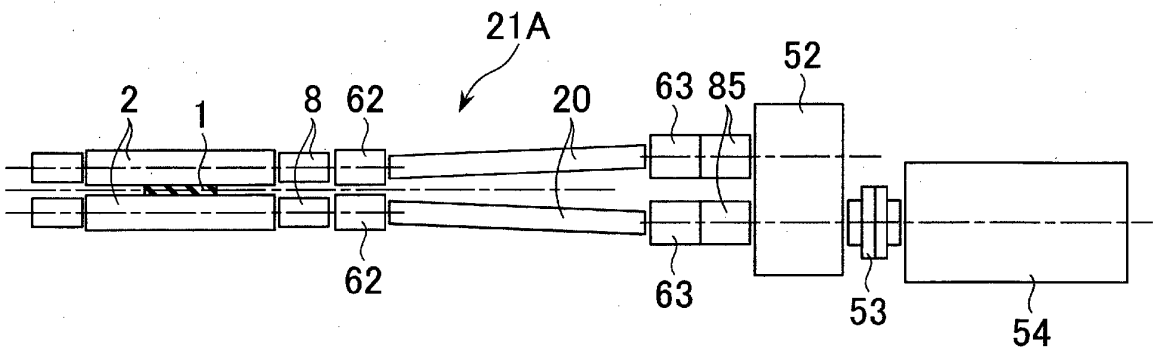


FIG.19B

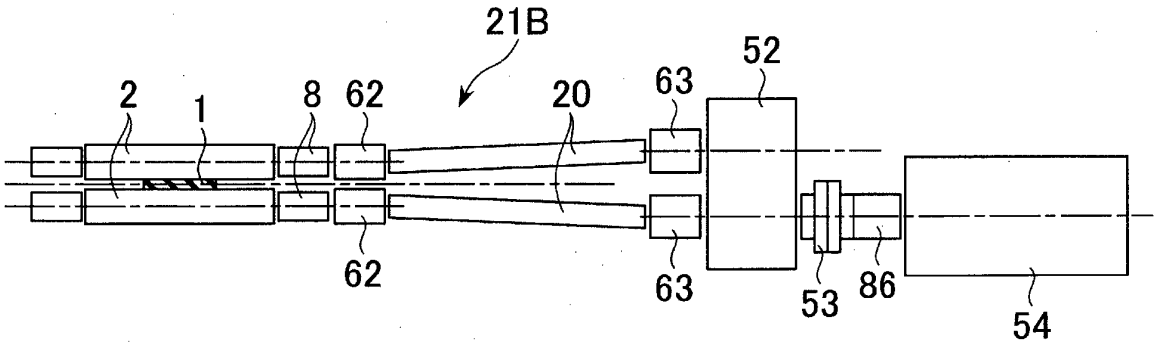


FIG.19C

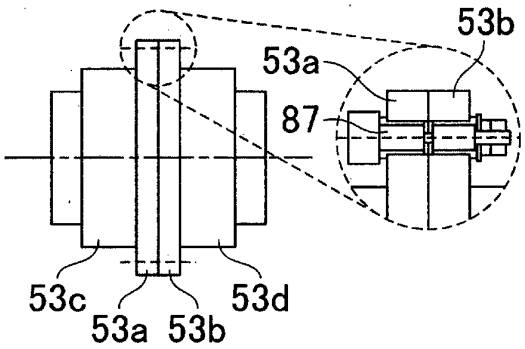


FIG.20A

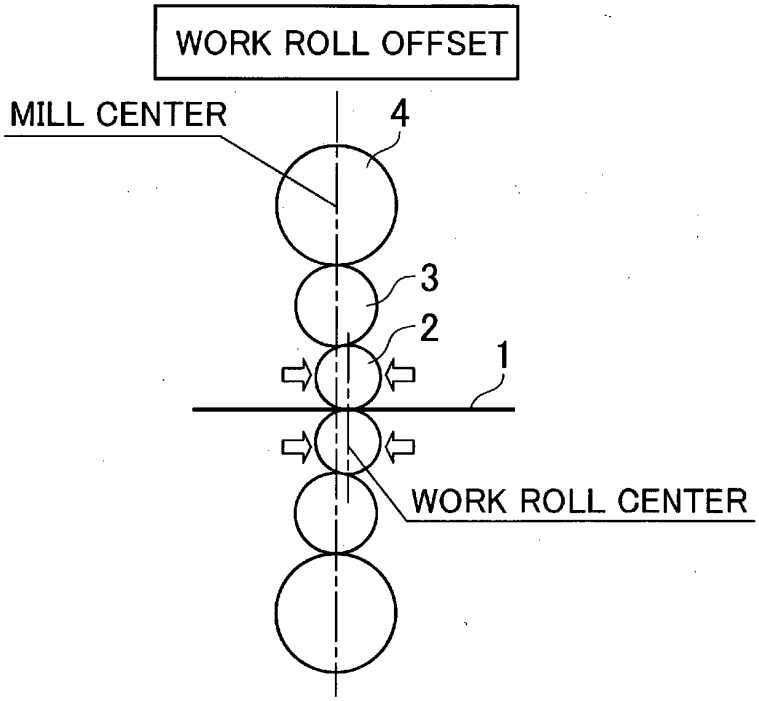


FIG.20B

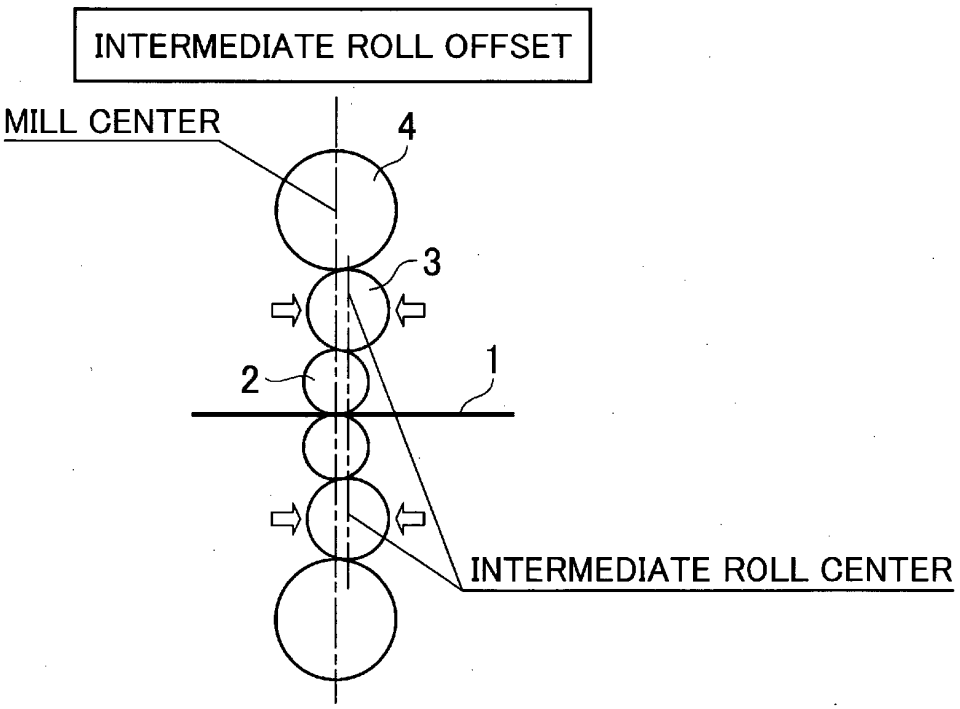


FIG.21

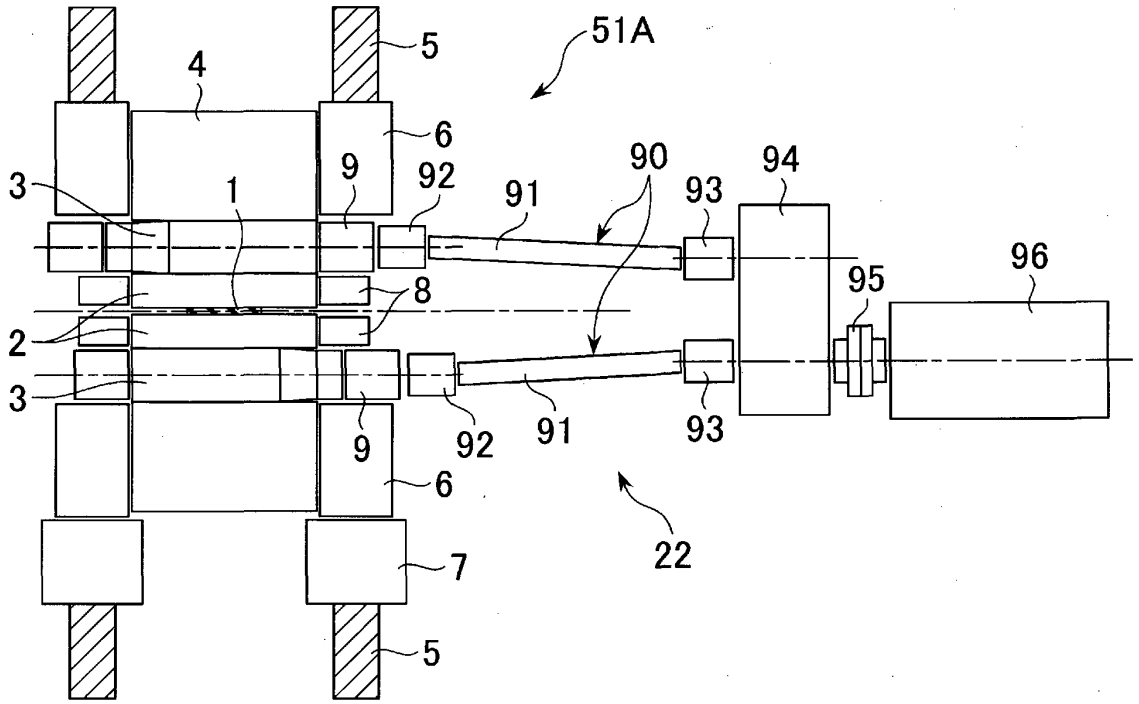


FIG.22

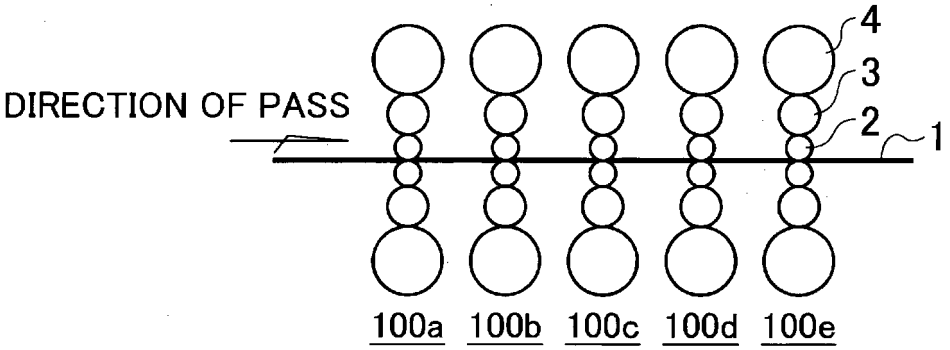

DIRECTION OF PASS
4
3
2
1
100a
100b
100c
100d
100e

FIG.23

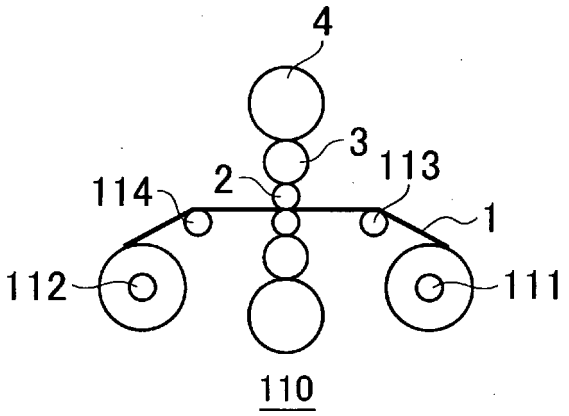

4
3
2
113
114
1
112
111
110

FIG.24

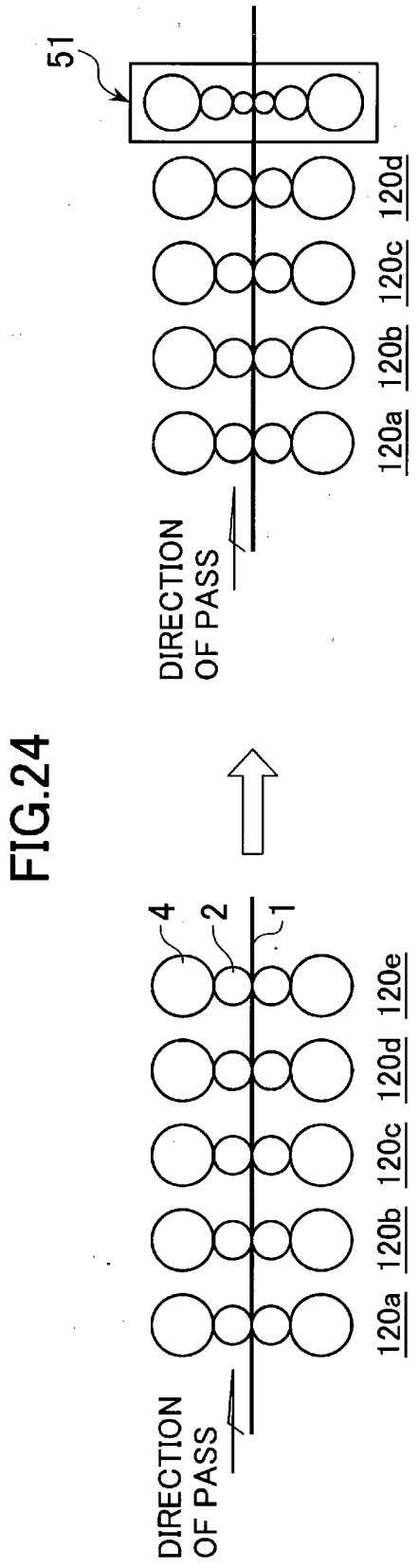

51
DIRECTION OF PASS
120a
120b
120c
120d
4
2
1
120e
DIRECTION OF PASS

FIG.25

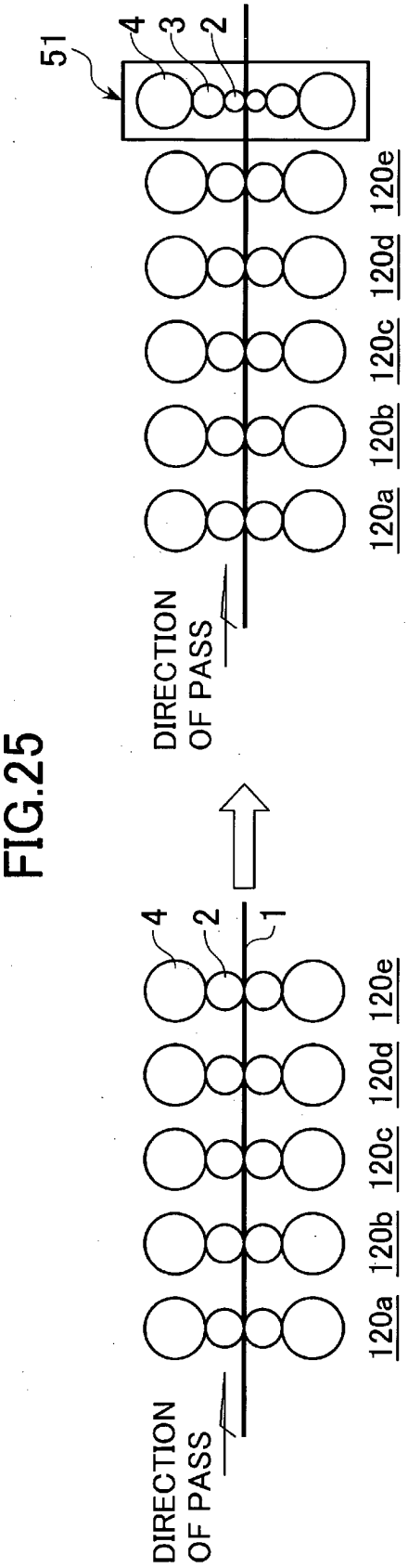

51
4
3
2
DIRECTION OF PASS
120a
120b
120c
120d
120e
4
2
1
DIRECTION OF PASS
120a
120b
120c
120d
120e

FIG.26

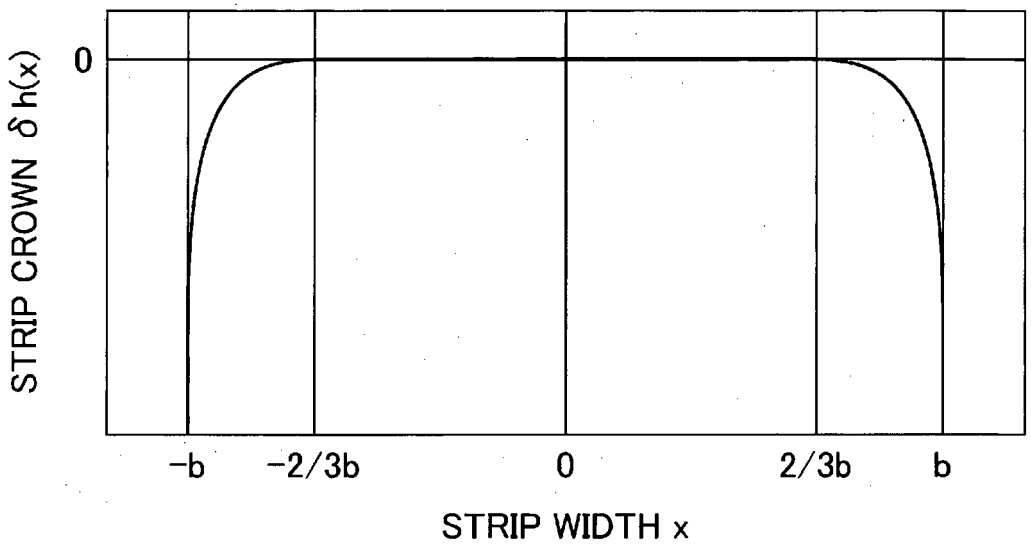
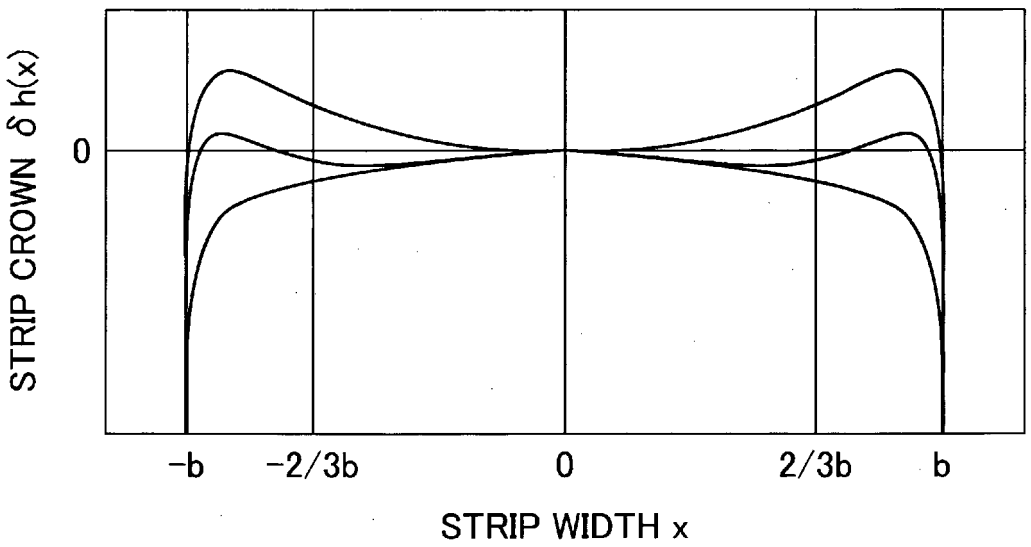

STRIP CROWN δh(x)
0
-b
-2/3b
0
2/3b
b
STRIP WIDTH x

FIG.27


STRIP CROWN δh(x)
0
-b
-2/3b
0
2/3b
b
STRIP WIDTH x

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- DE 10208389 A1 **[0001] [0005]**
- JP 3034928 A **[0004]**