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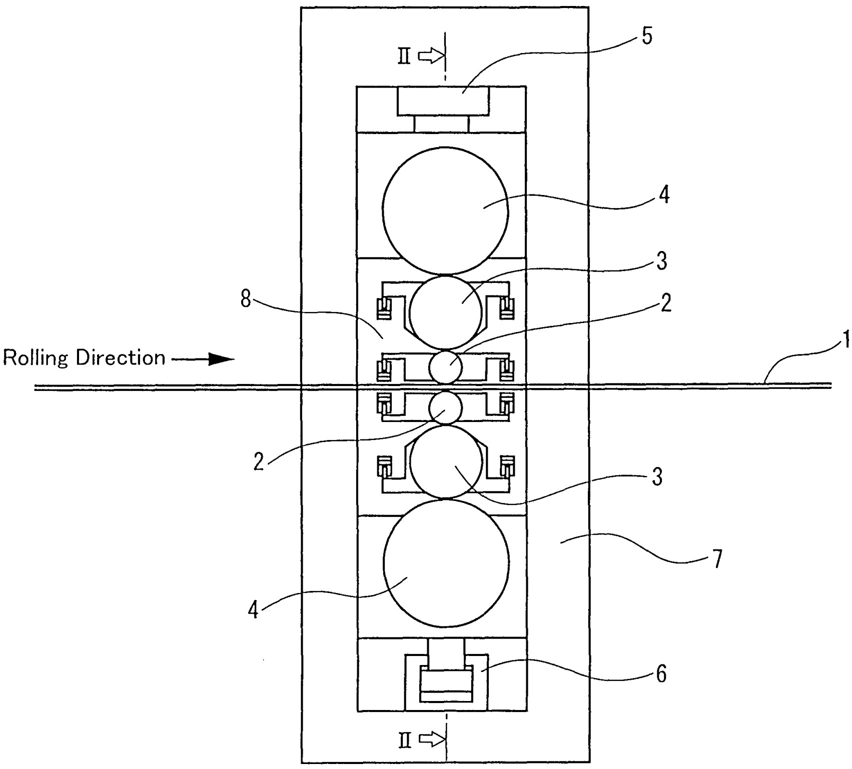
(54) **Rolling mill and tandem rolling mill having the same**

(57) A six-high rolling mill includes paired upper and lower work rolls (2) for rolling a strip (1) , paired upper and lower intermediate rolls (3) for supporting the paired upper and lower work rolls, and paired upper and lower back-up rolls (4) for supporting the paired upper and lower intermediate rolls, the six-high rolling mill having no supporting rolls inside and outside the reliable strip width of the work rolls. A similar four-high rolling mill lacks the intermediate rolls. In the six- or four-high rolling mill, the work rolls are driven, and the work rolls have a small diameter, and use a material having a high modulus of longitudinal elasticity, such as a cemented carbide or a ceramic.

Fig. 1



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Description

[Technical Field]

[0001] This invention relates to a rolling mill, which can render the diameter of work rolls small, and a tandem rolling mill equipped with the rolling mill.

[Background Art]

[0002] In a conventional so-called intermediate roll-drive six-high rolling mill (hereinafter referred to as a six-high mill), the minimum value of the work roll diameter is determined by the flexural rigidity value of the work rolls, which withstands the tangential force of the intermediate roll drive, if there are no support (supporting) rolls inside and outside the rollable strip width of the work rolls. According to Non-Patent Document 1, for example, this value is 180 mm to 380 mm in the case of a 4-feet width material upon the intermediate roll drive.
[0003] With work roll drive, the above-mentioned tangential force does not act, but differential tension, or a tension difference, between the inlet side and the outlet side of the rolling mill works. Within the range of the permissible strength of the drive system, therefore, the minimum value of the work roll diameter is determined by the flexural rigidity value of the work rolls, which withstands the differential tension, and at least the work roll diameter comparable to that mentioned above is feasible. With the work roll drive, moreover, at least the work roll diameter comparable to the above one can be achieved from this point of view, even in a four-high rolling mill (hereinafter referred to as a four-high mill).
[0004] A conventional six-high mill may have support rolls inside the rollable strip width of the work rolls. Further, a six-high mill, which has support bearings provided outside the rollable strip width of the work rolls, and applies horizontal bending to the work rolls via these support bearings, is disclosed in Patent Document 1.

[Citation List]

[Patent Literature]

[0005]

[Patent Document 1] JP-A-5-50109
[Patent Document 2] JP-A-60-238021
[Non-Patent Literature]

[0006]

[Non-Patent Document 1] "Industrial Machinery", May Issue, 1991 (pp. 56-60)

[summary of Invention]

[Technical Problem]

[0007] To meet a recent demand, an attempt has been made to roll a special steel, such as a harder stainless steel, by a six-high mill or four-high mill having no support rolls inside the rollable strip width of the work rolls. This attempt has posed a problem such that the aforementioned work roll diameter is too large and imposes a heavy load, thus failing to ensure a necessary reduction in thickness by rolling, and a problem such as poor gloss.
[0008] On the other hand, a six-high mill or four-high mill having support rolls inside the rollable strip width of the work rolls has involved the following problems: A space for the support roll portion is so small that sufficient strength and rigidity are difficult to ensure. Since there are support bearings for supporting the support rolls inside the rollable strip width of the work roll, moreover, marks of the support bearings are transferred to or produced in the plate via the support rolls and the work rolls, depending on their material.
[0009] A rolling mill having support bearings provided outside the rollable strip width of the work rolls has the following problems: Since the upper and lower support bearings are of the same phase, the bearings of a large size cannot be used, and the bearings applied cannot be adopted for heavy load, high torque rolling of a hard material which causes a great horizontal force.
[0010] The present invention has been proposed in the light of these circumstances. It is an object of the present invention to provide a rolling mill, which can render work rolls of a smaller diameter usable for the purpose of rolling a hard material, and can thereby obtain a strip with high productivity and of high product quality, and a tandem rolling mill

equipped with the rolling mill.

[Solution to Problem]

[0011] To solve the above-mentioned problems, the present invention provides a six-high rolling mill including upper and lower work rolls as a pair for rolling a metal strip, upper and lower intermediate rolls as a pair for supporting the work rolls, and upper and lower back-up rolls as a pair for supporting the upper and lower intermediate rolls as the pair, the six-high rolling mill having no supporting rolls inside and outside a rollable strip width of the work rolls, **characterized in that**
the work rolls are driven,
a material having a high modulus of longitudinal elasticity is used for the work roll, and
a minimum roll diameter of the work roll is intermediate between a minimum diameter upper limit Dmax1 and a minimum diameter lower limit Dmin1, and these parameters are expressed by the following equations:

$$\text{Minimum diameter upper limit Dmax1} = \text{D4max} \times B/K^{(1/4)}$$

where D4max is a minimum diameter upper limit of a conventional work roll with a strip width of 1,300 mm: 380 mm
B is a strip width (mm)/1,300 mm, and
K is a ratio of the high longitudinal modulus material to a conventional material (modulus of longitudinal elasticity of the high longitudinal modulus material/modulus of longitudinal elasticity of the conventional material (21,000 kg/mm^2))

$$\text{Minimum diameter lower limit Dmin1} = \text{D4min} \times B/K^{(1/4)}$$

where D4min is a minimum diameter lower limit of the conventional work roll with the strip width of 1,300 mm: 180 mm.

[0012] To solve the above-mentioned problems, the present invention also provides a four-high rolling mill including upper and lower work rolls as a pair for rolling a metal strip, and upper and lower back-up rolls as a pair for supporting the work rolls, the four-high rolling mill having no supporting rolls inside and outside a rollable strip width of the work rolls, **characterized in that**
the work rolls are driven,
a material having a high modulus of longitudinal elasticity is used for the work roll, and
a minimum roll diameter of the work roll is intermediate between a minimum diameter upper limit Dmax1 and a minimum diameter lower limit Dmin1, and these parameters are expressed by the following equations:

$$\text{Minimum diameter upper limit Dmax1} = \text{D4max} \times B/K^{(1/4)}$$

where D4max is a minimum diameter upper limit of a conventional work roll with a strip width of 1,300 mm: 380 mm
B is a strip width (mm)/1,300 mm, and
K is a ratio of the high longitudinal modulus material to a conventional material (modulus of longitudinal elasticity of the high longitudinal modulus material/modulus of longitudinal elasticity of the conventional material (21,000 kg/mm^2))

$$\text{Minimum diameter lower limit Dmin1} = \text{D4min} \times B/K^{(1/4)}$$

where D4min is a minimum diameter lower limit of the conventional work roll with the strip width of 1,300 mm: 180 mm.

[0013] The six- or four-high rolling mill is **characterized in that** the ratio of the high longitudinal modulus material to the conventional material (longitudinal modulus ratio), K, is 1.2 to 3.0. If the work roll is a composite material roll, an equivalent modulus of longitudinal elasticity is preferably used as the modulus of longitudinal elasticity.

[0014] To solve the above-mentioned problems, the present invention further provides a tandem rolling mill including a plurality of rolling mill stands arranged therein, **characterized in that** the six-high rolling mill or the four-high rolling mill is provided as at least one of the stands.

[Advantageous Effects of Invention]

[0015] According to the features of the present invention, the high longitudinal modulus material is used for the work roll. By so doing, the flexural rigidity of the work roll is ensured, and the diameter of the work roll can be rendered small by an amount corresponding to the high rigidity. Consequently, edge drops can be reduced, surface gloss can be improved, and the minimum rollable strip thickness can be decreased. Furthermore, the rolling mill and the tandem rolling mill can be applied to a heavy load, high torque rolling mill for a hard material. They are preferred particularly for cold rolling.

[Brief Description of Drawings]

[0016]

[Fig. 1] Fig. 1 is a front sectional view of a six-high mill showing Embodiment 1 of the present invention.
[Fig. 2] Fig. 2 is a sectional view taken along line II-II in Fig. 1.
[Fig. 3] Fig. 3 is an explanation drawing of a composite roll.
[Fig. 4] Fig. 4 is an explanation drawing of inlet side-outlet side differential tension.
[Fig. 5] Fig. 5 is an explanation drawing of the deflection of a work roll.
[Fig. 6] Fig. 6 is a graph showing a comparison between the work roll minimum diameter upper limits Dmax' s in Embodiment 1 and a conventional example.
[Fig. 7] Fig. 7 is a graph showing a comparison between the work roll minimum diameter lower limits Dmin's in them.
[Fig. 8A] Fig. 8A is an explanation drawing of a work roll offset showing an applied example of Embodiment 1.
[Fig. 8B] Fig. 8B is an explanation drawing of load imposed on the work roll in the applied example.
[Fig. 9A] Fig. 9A is an explanation drawing of an intermediate roll offset showing another applied example of Embodiment 1.
[Fig. 9B] Fig. 9B is an explanation drawing of load imposed on the work roll in the another applied example.
[Fig. 10] Fig. 10 is an explanation drawing of a work roll shift of a six-high mill showing still another applied example of Embodiment 1.
[Fig. 11] Fig. 11 is a front sectional view of a four-high mill showing Embodiment 2 of the present invention.
[Fig. 12] Fig. 12 is a sectional view taken along line XII-XII in Fig. 11.
[Fig. 13] Fig. 13 is an explanation drawing of a work roll shift of a four-high mill showing an applied example of Embodiment 2.
[Fig. 14] Fig. 14 is an explanation drawing of the application of the present invention to a tandem rolling mill.

[Description of Embodiments]

[0017] A rolling mill and a tandem rolling mill equipped therewith, according to the present invention, will be described in detail by the following embodiments using drawings.

[Embodiment 1]

[0018] Fig. 1 is a front sectional view of a six-high mill showing Embodiment 1 of the present invention. Fig. 2 is a sectional view taken along line II-II in Fig. 1. Fig. 3 is an explanation drawing of a composite roll. Fig. 4 is an explanation drawing of inlet side-outlet side differential tension. Fig. 5 is an explanation drawing of the deflection of a work roll. Fig. 6 is a graph showing a comparison between the work roll minimum diameter upper limits Dmax' s in Embodiment 1 and a conventional example. Fig. 7 is a graph showing a comparison between the work roll minimum diameter lower limits Dmin' s in them. Fig. 8A is an explanation drawing of a work roll offset showing an applied example of Embodiment 1. Fig. 8B is an explanation drawing of load imposed on the work roll in the applied example. Fig. 9A is an explanation drawing of an intermediate roll offset showing another applied example of Embodiment 1. Fig. 9B is an explanation drawing of load imposed on the work roll in the another applied example. Fig. 10 is an explanation drawing of a work roll shift of a six-high mill showing still another applied example of Embodiment 1.

[0019] As shown in Figs. 1 and 2, a strip 1, which is a material to be rolled, is rolled by upper and lower work rolls 2 as a pair. These paired upper and lower work rolls 2 are in contact with, and supported by, upper and lower intermediate rolls 3 as a pair. These paired upper and lower intermediate rolls 3 are in contact with, and supported by, upper and lower back-up rolls 4 as a pair.

[0020] The upper back-up roll 4 is supported by bearing housings 17a, 17c via bearings (not shown), and these bearing housings 17a, 17c are supported by housings 7 (7a, 7b) via pass line adjusting devices 5a, 5b such as worm jacks or taper wedges and stepped rocker plates. Here, load cells may be incorporated inside the pass line adjusting devices

5a, 5b to measure a rolling load.

[0021] The lower back-up roll 4 is supported by bearing housings 17b, 17d via bearings (not shown), and these bearing housings 17b, 17d are supported by the housings 7a, 7b via hydraulic cylinders 6 (6a, 6b).

[0022] A material having a high modulus of longitudinal elasticity is used for the paired upper and lower work rolls 2. An example of the material having the high modulus of longitudinal elasticity is a cemented carbide such as tungsten carbide (modulus of longitudinal elasticity: 53,000 kg/mm^2), or a ceramic (modulus of longitudinal elasticity: 31,000 kg/mm^2). Special forged steel (modulus of longitudinal elasticity: 21,000 kg/mm^2) or the like has been used as a conventional material.

[0023] It is preferred that the ratio of the high longitudinal modulus material to the conventional material (longitudinal modulus ratio), K, be set at 1.2 to 3.0.

[0024] As shown in Fig. 3, moreover, a roll composite material using a high longitudinal modulus material as a roll surface layer material 2A and a conventional material as a roll internal layer material 2B may be used for the paired upper and lower work rolls 2. The modulus of longitudinal elasticity used in this case is an equivalent modulus of longitudinal elasticity shown below.

[0025] The equivalent modulus of longitudinal elasticity, Ee, is expressed by the following equation (1)

$$Ee = (d1^4 + (d2^4 - d1^4) \times E2/E1)/d2^4 \qquad \text{Equation (1)}$$

where d2 is the outer diameter of the roll surface layer material 2A, E2 is the modulus of longitudinal elasticity of the roll surface layer material 2A, d1 is the outer diameter of the roll internal layer material 2B, and E1 is the modulus of longitudinal elasticity of the roll internal layer material 2B.

[0026] Further, bearing housings 13a to 13d are mounted on roll neck portions of the paired upper and lower work rolls 2 via bearings (not shown). These bearing housings 13a to 13d are furnished with bending cylinders 14a to 14d for imparting roll bending. By so doing, roll bending is imparted to the work rolls 2.

[0027] Here, rolling load is imparted by the hydraulic cylinders 6a, 6b, and rolling torque is transmitted to the work rolls 2 by spindles (not shown). The paired upper and lower intermediate rolls 3 have roll shoulders 3a, whose roll diameter decreases, at the positions of the roll barrel ends in vertical point symmetry with respect to the center of the strip width of the strip 1.

[0028] The paired upper and lower intermediate rolls 3 are supported by bearing housings 15a to 15d via bearings (not shown). The paired upper and lower intermediate rolls 3 are axially movable by shifting devices (not shown) via the drive-side bearing housings 15c, 15d. Further, these bearing housings 15a to 15d are furnished with bending cylinders 16a to 16d for imparting roll bending. By so doing, roll bending is imparted to the intermediate rolls 3.

[0029] Deflection of the work roll by the rolling mill inlet side-outlet side differential tension will be described using Fig. 4 and Fig. 5.

[0030] As shown in Fig. 4, if the inlet-side tension of the rolling mill is designated as Tb, and the outlet-side tension of the rolling mill is designated as Tf, differential tension which is the difference between Tb and Tf is exerted on the work rolls 2. Since the number of the bearings for the work roll is one each on the operating side and on the drive side, the supporting conditions for simple support shown in Fig. 5 apply. Horizontal deflection δ s of the work roll in this case is expressed by the following equation (2), where F represents the differential tension per unit length, L represents the support spacing, Dc represents the diameter of the conventional work roll 2, Ic represents the second moment of area of the conventional work roll diameter, and Ec represents the modulus of longitudinal elasticity (21,000 kg/mm^2) of the material (special forged steel) for the conventional work roll:

$$\delta s = 5 \times F \times L^4/(384 \times Ec \times Ic) \; ..... \; \text{Equation (2)}$$

where

$$Ic = \pi \times Dc^4/64$$

$$F = (Tf - Tb)/L/2$$

[0031] A material with a high modulus of longitudinal elasticity is used for the paired upper and lower work rolls 2. Deflection δ r in the horizontal direction of the work roll 2 in this case is expressed by the following equation (3), where Dr represents the diameter of the work roll 2 of Embodiment 1, Ir represents the second moment of area of the diameter of the work roll of Embodiment 1, and Er represents the modulus of longitudinal elasticity of the material for the work roll of Embodiment 1.

$$\delta r = 5 \times F \times L^4 / (384 \times Er \times Ir) \text{ ..... Equation (3)}$$

where $Ir = \pi \times Dr^4/64$
Assuming that $\delta r = \delta s$, Dr is expressed by the following equation (4):

$$Dr = Dc/K^{(1/4)} \text{ .... Equation (4)}$$

[0032] On the other hand, the minimum roll diameter of the work roll is intermediate between the minimum diameter upper limit Dmax1 and the minimum diameter lower limit Dmin1, and these parameters are expressed by the following equation (5):

$$\text{Minimum diameter upper limit } Dmax1 = D4max \times B/K^{(1/4)} \text{ ... Equation (5)}$$

where D4max; minimum diameter upper limit of conventional work roll with strip width of 1,300 mm: 380 mm
B; strip width (mm)/1,300 mm
K; high longitudinal modulus material/conventional material ratio (modulus of longitudinal elasticity of high longitudinal modulus material/modulus of longitudinal elasticity of conventional material (21,000 kg/mm^2))
The minimum diameter upper limit Dmax1 per strip width in Embodiment 1 is shown in Fig. 6. K=2.5, provided that the material for the work roll was a cemented carbide.

$$\text{Minimum diameter lower limit } Dmin1 = D4min \times B/K^{(1/4)} \text{ ... Equation (6)}$$

where D4min; minimum diameter lower limit of conventional work roll with strip width of 1,300 mm: 180 mm
The minimum diameter lower limit Dmin1 per strip width in the present embodiment is shown in Fig. 7. K=2.5, provided that the material for the work roll was the cemented carbide.

[0033] In the present embodiment, as describe above, the work roll 2 composed of a cemented carbide or a ceramic material as a high longitudinal modulus material is used in the six-high mill having no supporting rolls inside and outside the rollable strip width of the work rolls 2. Thus, the flexural rigidity of the work roll is ensured, and the diameter of the work roll can be rendered small by an amount corresponding to the high rigidity. Consequently, the strip 1 of high product quality can be obtained with high productivity by the rolling of a hard material.

[0034] As shown in Figs. 8A and 8B, the work rolls 2 of the high longitudinal modulus material may be offset variably, according to the magnitude of the inlet side-outlet side differential tension (Tf-Tb)/2, toward the inlet side in the rolling direction in the horizontal direction (see an offset amount α in Fig. 8A). By so doing, the inlet side-outlet side differential tension (Tf-Tb)/2 is decreased by the offset horizontal component force Fa of the rolling load Q, so that the total force in the horizontal direction exerted on the work roll 2 is decreased. In Fig. 8B, Fb represents the offset vertical component force of the rolling load Q.

[0035] As a result, the advantage that the deflection of the work roll 2 can be further diminished is produced.
The total force Fw in the horizontal direction exerted on the work roll 2 is expressed by the following equation (7):

$$Fw = (Tf-Tb)/2 - Q \times \alpha / ((Dw+DI)/2) \text{ ..... Equation (7)}$$

where Dw represents the diameter of the work roll, and DI represents the diameter of the intermediate roll.

[0036] As shown in Figs. 9A and 9B, the intermediate rolls 3 may be offset variably, according to the magnitude of the inlet side-outlet side differential tension (Tf-Tb)/2, toward the outlet side in the rolling direction in the horizontal direction (see an offset amount β in Fig. 9A). By so doing, the inlet side-outlet side differential tension (Tf-Tb)/2 is decreased by the offset horizontal component force Fa of the rolling load Q, so that the total force in the horizontal direction exerted on the work roll 2 of the high longitudinal modulus material is decreased. In Fig. 9B, Fb represents the offset vertical component force of the rolling load Q.

[0037] As a result, the advantage is produced that the deflection of the work roll 2 can be further diminished. The total force Fw in the horizontal direction exerted on the work roll 2 is expressed by the following equation (8):

$$Fw = (Tf-Tb)/2-Q\times \beta /((Dw+DI)/2) \quad \ldots\ldots \text{Equation (8)}$$

where Dw represents the diameter of the work roll, and DI represents the diameter of the intermediate roll.

[0038] In the present embodiment, the paired upper and lower work rolls 2 are not structured to be shifted in the axial direction. As will be described below, however, the work roll 2 may have a structure in which it can be shifted in the axial direction. The shift structure for the work roll is, for example, a structure as shown in Patent Document 2.

[0039] As shown in Fig. 10, the upper and lower work rolls 2 as a pair have roll shoulders 2a, which taper, at the positions of the roll barrel ends in vertical point symmetry with respect to the center of the strip width of the strip 1. Roll neck portions of the paired upper and lower work rolls 2 are mounted with bearings (not shown) on the operating side and on the drive side. The paired upper and lower work rolls 2 are movable in the axial direction by shift cylinders (not shown) via the drive-side bearings (not shown).

[0040] Next, an explanation will be offered for a method of decreasing edge drops by the shift of the work roll 2 having the tapered roll shoulder 2a. The work rolls 2 are provided with the tapered roll shoulders 2a in vertical point symmetry, and the distances from the positions of the roll shoulders to the plate ends are designated as δw and δd. A strip thickness gauge (not shown) is provided for measuring the strip thickness at one point or a plurality of points in the vicinity of strip edge portions on the operating side and the drive side on the outlet side of the rolling mill.

[0041] If the strip thickness at the one point or the plurality of points in the vicinity of the strip edge portion, which has been measured on the operating side, is smaller than a predetermined strip thickness, the upper work roll 2 is shifted in the direction of the roll shaft width narrowing. That is, the upper work roll 2 is shifted in a direction in which δ w is increased. Conversely, if the measured strip thickness at the site in the vicinity of the strip edge portion is larger than the predetermined strip thickness, the upper work roll 2 is shifted in the direction of the roll shaft width broadening. That is, the upper work roll 2 is shifted in a direction in which δw is decreased.

[0042] If the strip thickness at the one point or the plurality of points in the vicinity of the strip edge portion, which has been measured on the drive side, is different from the predetermined strip thickness, the lower work roll 2 is similarly shifted so that the above strip thickness equals the predetermined strip thickness. Essentially, the work roll diameter can be rendered small by applying the work roll 2 of the high longitudinal modulus material. Thus, the rolling load can be decreased in conformity with the small diameter. This makes it possible to curtail a sharp decrease in thickness at the strip edge portion, which is called an edge drop becoming the cause of a decreased yield.

[0043] The combined use of the small-diameter work roll and the work roll shift mentioned above can minimize the tapered roll shoulder 2a or minimize the shift distance δw or δd. This technology is preferred, in particular, for rolling of a brittle material, such as an electromagnetic steel sheet, which is susceptible to these values and is apt to splinter. Fig. 10 describes the mill of Fig. 1 as a representative, but the mill with the variably offset work rolls in Figs. 8A, 8B or the mill with the variably offset intermediate rolls in Figs. 9A, 9B may be used.

[0044] The present embodiment shows an example in which the paired upper and lower intermediate rolls 3 have the roll shoulders 3a, which decrease in roll diameter, at the positions of the roll barrel ends in vertical point symmetry with respect to the center of the strip width of the strip 1. However, the paired upper and lower intermediate rolls 3 may be structured to have S-curved roll crowns in vertical point symmetry with respect to the center of the strip width of the strip 1, and to be shifted in the axial direction, as shown in Non-Patent Document 1. In this case, the ability to control shape is lower than in the six-high mill having the roll shoulder 3a, but is higher than in the four-high mill. Moreover, the aforementioned work roll shift shown in Fig. 10 may be applied to this mill.

[Embodiment 2]

[0045] Fig. 11 is a front sectional view of a four-high mill showing Embodiment 2 of the present invention. Fig. 12 is a sectional view taken along line XII-XII in Fig. 11. Fig. 13 is an explanation drawing of a work roll shift of a four-high mill showing an applied example of Embodiment 2.

[0046] The rolling mill of the present embodiment is a four-high rolling mill, and is configured to remove the set of the paired upper and lower intermediate rolls 3, the bearing housings 15a to 15d, and the bending cylinders 16a to 16d from the six-high rolling mill which represents Embodiment 1, as shown in Figs. 11 and 12. In this case, the plate shape control ability declines greatly, but the structure is further simplified.

[0047] In the present embodiment, the paired upper and lower work rolls 2 do not show a structure for shift in the axial direction. As shown in Fig. 13, however, the work rolls 2 may be structured to have roll shoulders 2a, which taper, at the positions of the roll barrel ends in vertical point symmetry with respect to the center of the strip width of the strip 1, and to be shiftable in the axial direction. According to this configuration, edge drops can be decreased using a simpler structure.

[0048] The above-mentioned applied example is an example of a structure in which the paired upper and lower work rolls 2 have the tapered roll shoulders 2a at the positions of the roll barrel ends in vertical point symmetry with respect to the center of the strip width of the strip 1, and are shiftable in the axial direction. However, the paired upper and lower work rolls 2 may be structured to have S-curved roll crowns in vertical point symmetry with respect to the center of the strip width of the strip 1, and to be shifted in the axial direction, as shown in Non-Patent Document 1. In this case, the ability to control shape is higher than in the four-high mill shown in Fig. 13.

[0049] If the rolling mill with the small-diameter work rolls according to the present invention is applied to a tandem rolling mill, its application to No. 1 stand, as shown in Fig. 14, enables the small-diameter work rolls of the high longitudinal modulus material to impart a great reduction in thickness. When it is applied to the final stand, i.e., No. 4 stand in the drawing, a thinner strip can be rolled by the small-diameter work rolls of the high longitudinal modulus material. It goes without saying that the rolling mills with the small-diameter work rolls according to the present invention may be applied to all of No. 1 stand to No. 4 stand. This makes it possible to roll a thinner, harder material. Fig. 14 illustrates the six-high mill as a representative of the rolling mill with the small-diameter work rolls according to the present invention, but a four-high mill can be applied similarly.

[Reference Signs List]

[0050]

1	Strip
2	Work roll
3	Intermediate roll
4	Back-up roll
5a, 5b	Pass line adjusting device
6a, 6b	Hydraulic cylinder
7a, 7b	Housing
13a to 13d	Work roll bearing housing
15a to 15d	Intermediate roll bearing housing
17a to 17d	Back-up roll bearing housing
14a to 14d	Work roll bending cylinder
16a to 16d	Intermediate roll bending cylinder

Claims

1. A rolling mill including upper and lower work rolls (2) as a pair for rolling a metal strip (1), the rolling mill having no supporting rolls inside and outside a rollable strip width of the work rolls, **characterised in that**
the work rolls are driven,
a material having a high modulus of longitudinal elasticity is used for the work roll, and
a minimum roll diameter of the work roll is intermediate between a minimum diameter upper limit Dmax1 and a minimum diameter lower limit Dmin1, and these parameters are expressed by the following equations:

$$\text{Minimum diameter upper limit } Dmax1 = D4max \times B/K^{(1/4)}$$

where D4max is a minimum diameter upper limit of a conventional work roll with a strip width of 1,300 mm: 380 mm
B is a strip width (mm) /1,300 mm, and
K is a ratio of the high longitudinal modulus material to a conventional material (modulus of longitudinal elasticity of the high longitudinal modulus material/modulus of longitudinal elasticity of the conventional material (21,000 kg/mm^2))

$$\text{Minimum diameter lower limit Dmin1} = \text{D4min} \times B/K^{(1/4)}$$

where D4min is a minimum diameter lower limit of the conventional work roll with the strip width of 1,300 mm: 180 mm.

2. The rolling mill of claim 1, wherein the rolling mill is a six-high rolling mill further including upper and lower intermediate rolls (3) as a pair for supporting the work rolls, and upper and lower back-up rolls (4) as a pair for supporting the upper and lower intermediate rolls as the pair.

3. The rolling mill of claim 1, wherein the rolling mill is a four-high rolling mill further including upper and lower back-up rolls (4) as a pair for supporting the work rolls.

4. The rolling mill of any preceding claim, **characterised in that** the ratio of the high longitudinal modulus material to the conventional material (longitudinal modulus ratio), K, is 1.2 to 3.0.

5. A tandem rolling mill including a plurality of rolling mill stands arranged therein, **characterised in that** the rolling mill of any preceding claim is provided as at least one of the stands.

Fig. 1

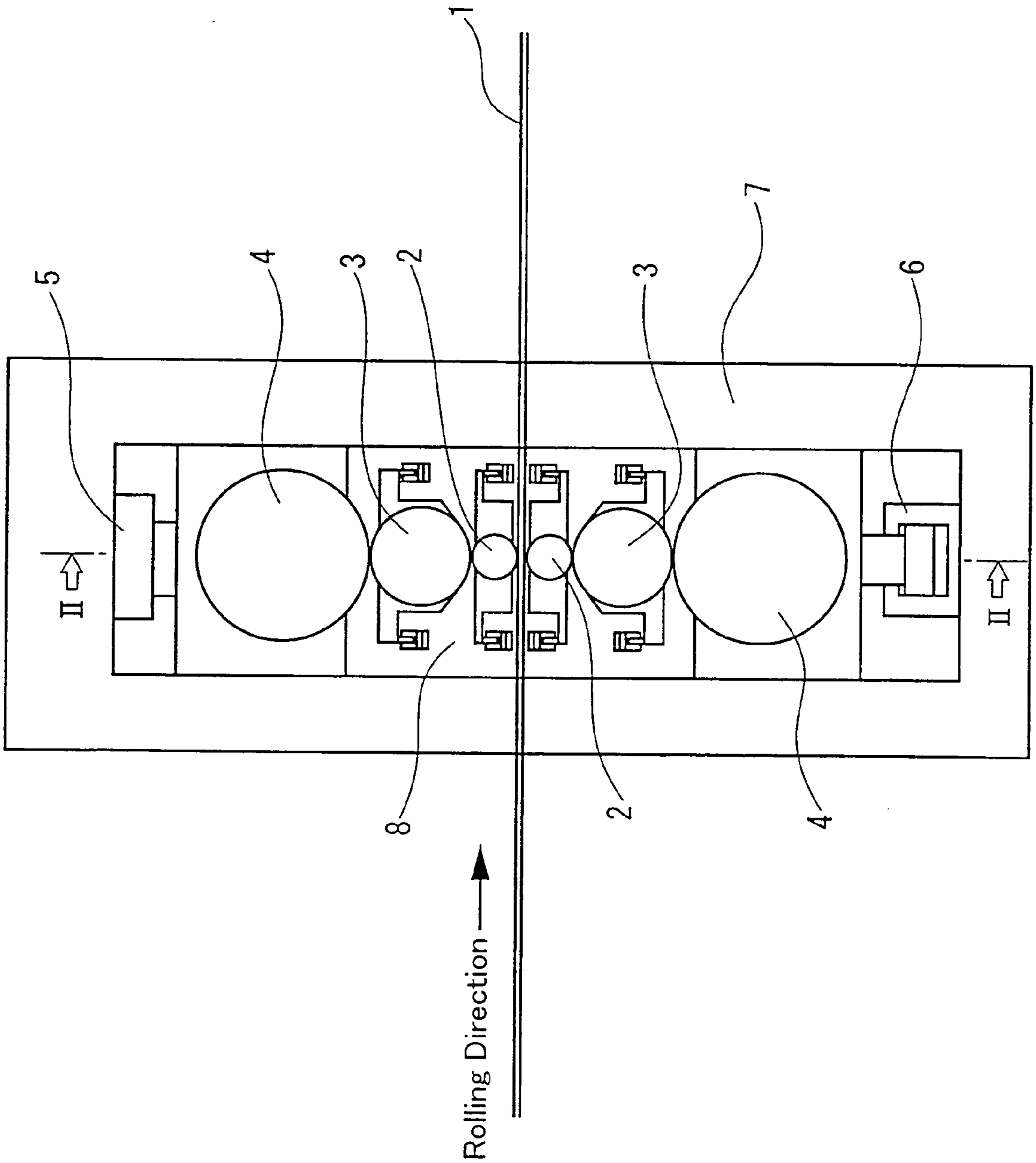
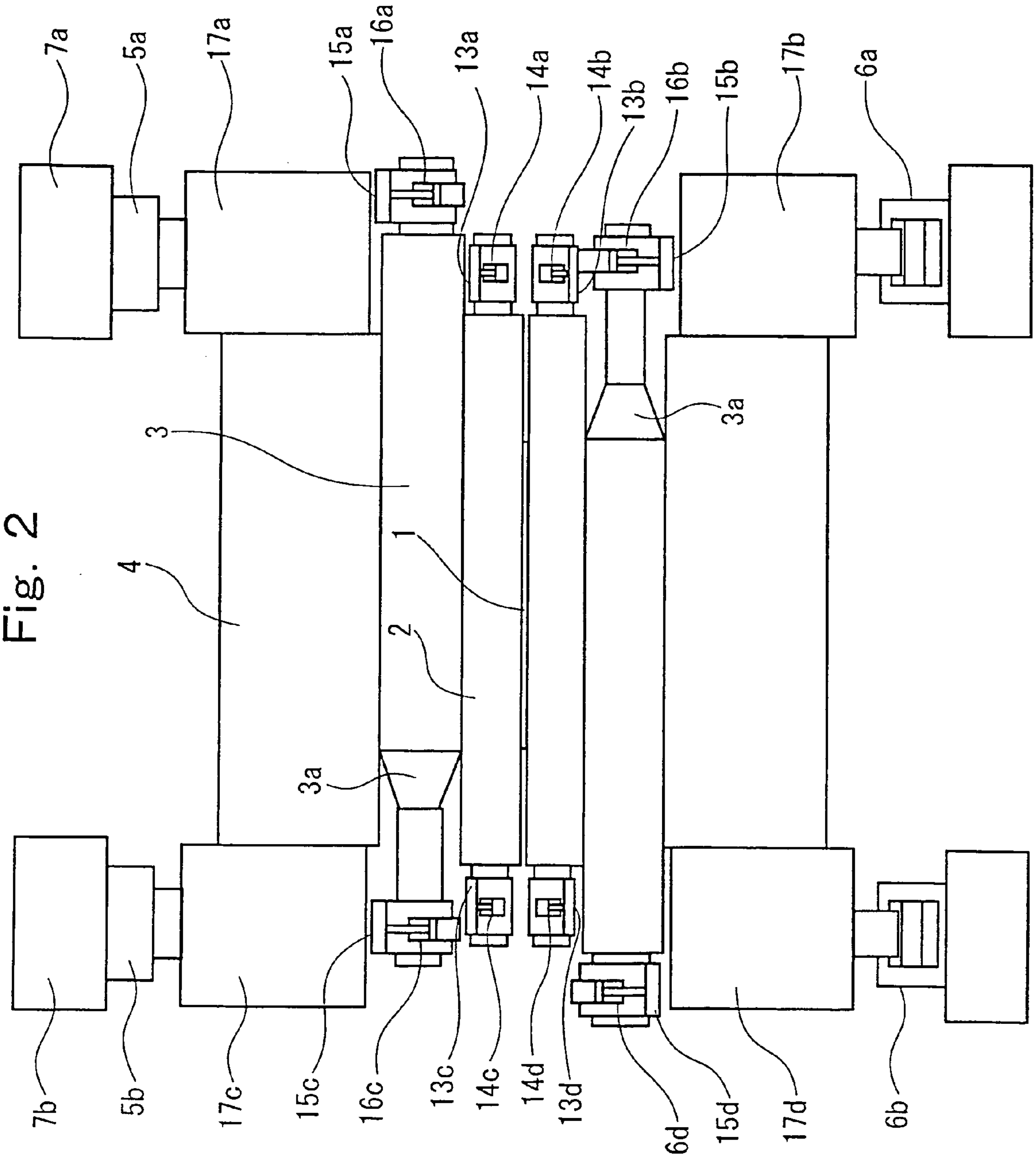


Fig. 2


7a
5a
17a
15a
16a
13a
14a
14b
13b
16b
15b
17b
6a
3
4
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2
3a
3a
7b
5b
17c
15c
16c
13c
14c
14d
13d
16d
15d
17d
6b

Fig. 3

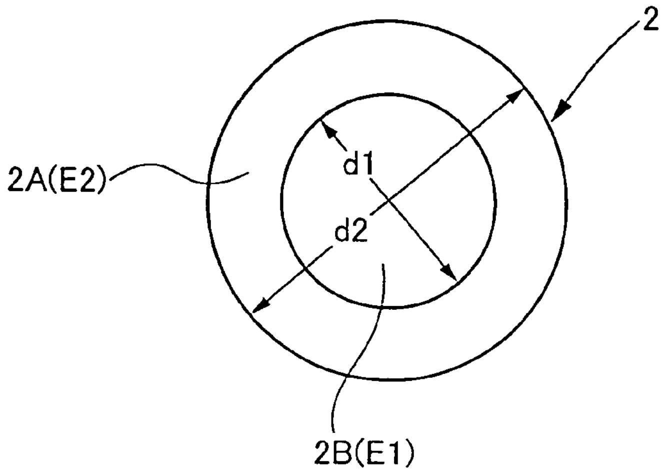


Fig. 4

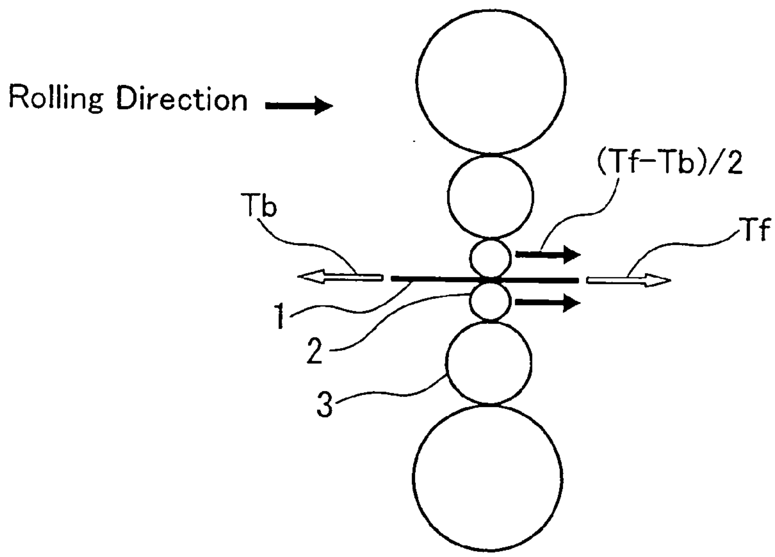


Fig. 5

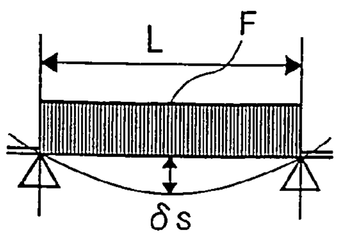
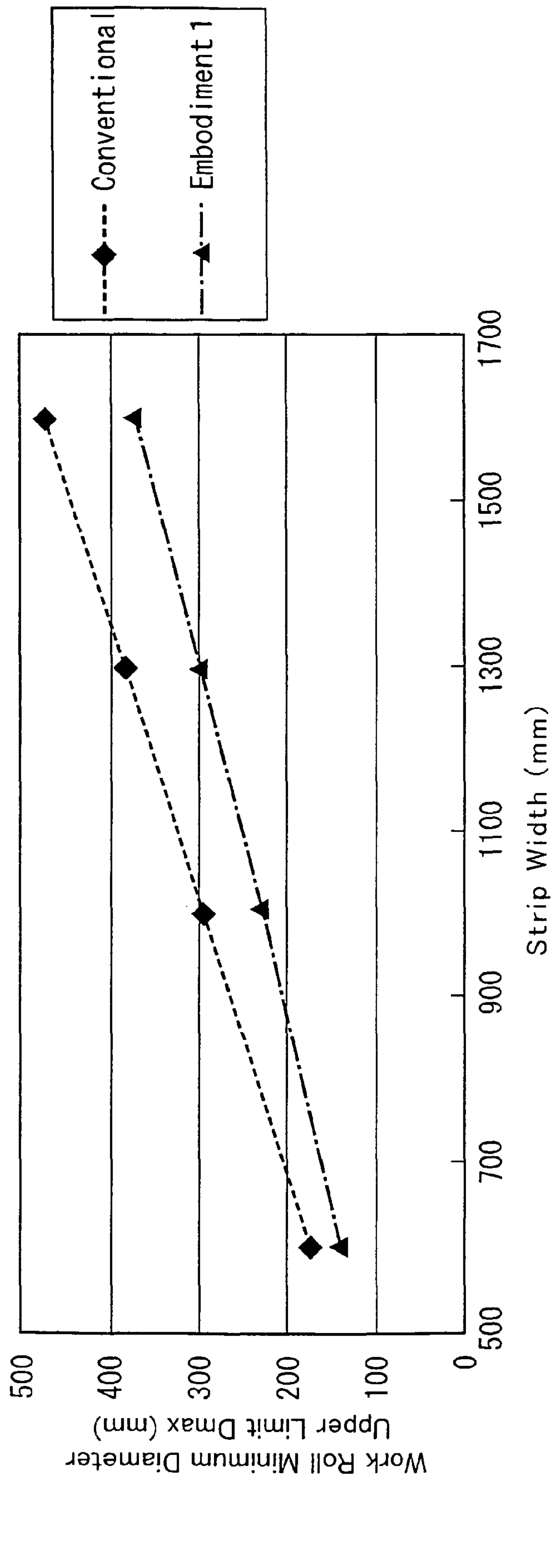


Fig. 6



Work Roll Minimum Diameter Upper Limit Dmax (mm)
0
100
200
300
400
500
Strip Width (mm)
500
700
900
1100
1300
1500
1700
Conventional
Embodiment 1

Fig. 7

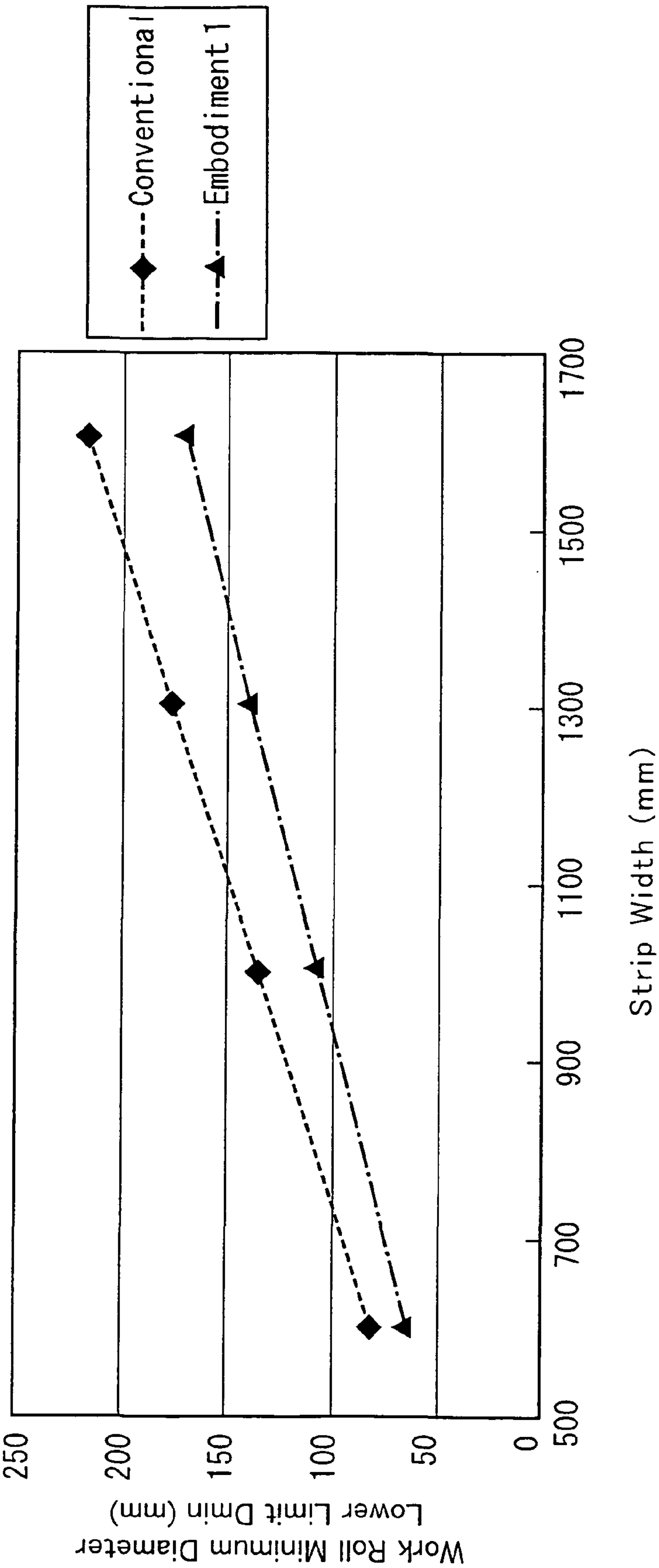

Conventional
Embodiment 1
Work Roll Minimum Diameter
Lower Limit Dmin (mm)
250
200
150
100
50
0
500
700
900
1100
1300
1500
1700
Strip Width (mm)

Fig. 8A

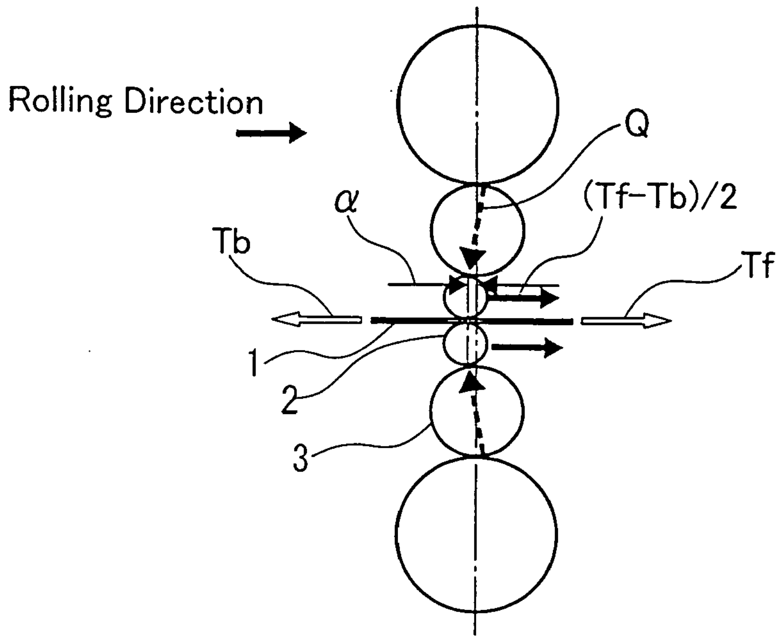


Fig. 8B

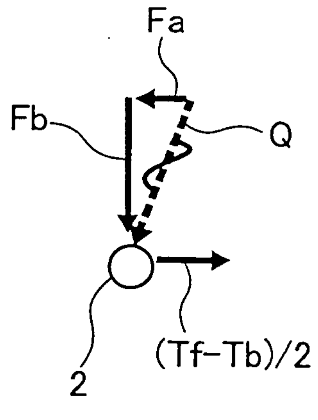


Fig. 9A

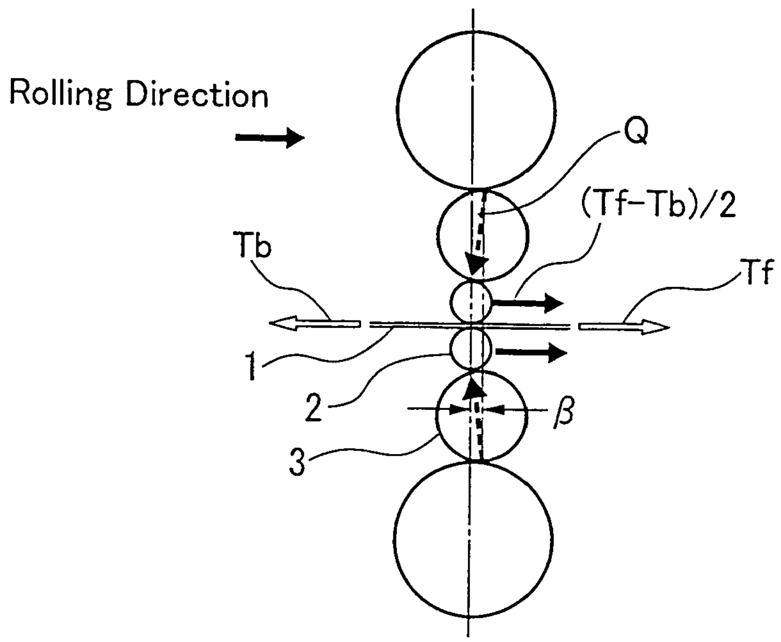


Fig. 9B

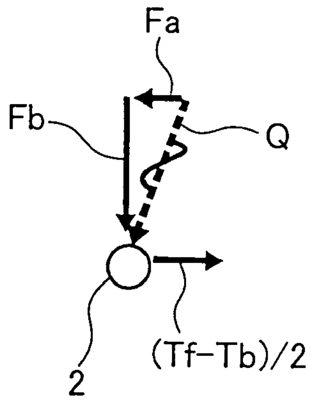


Fig. 10

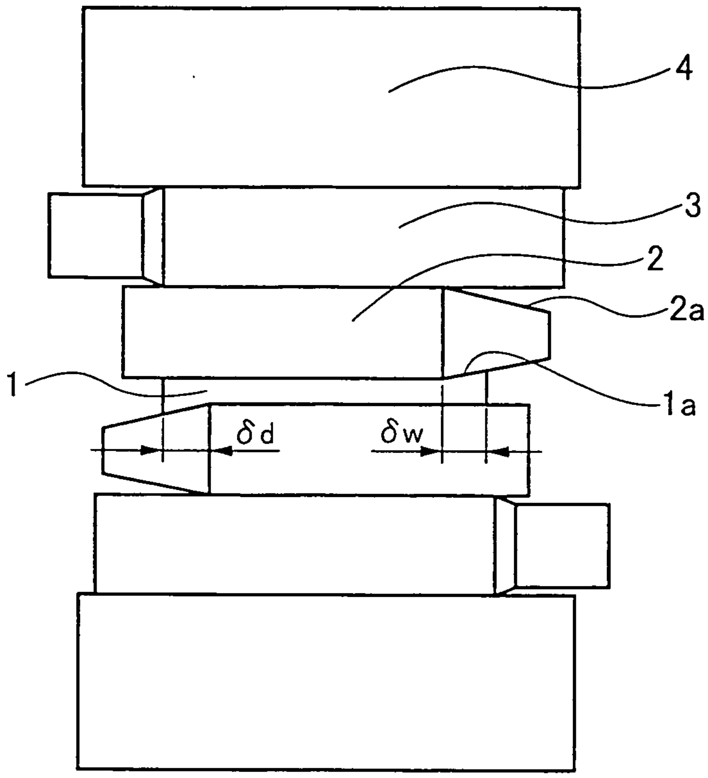


Fig. 11

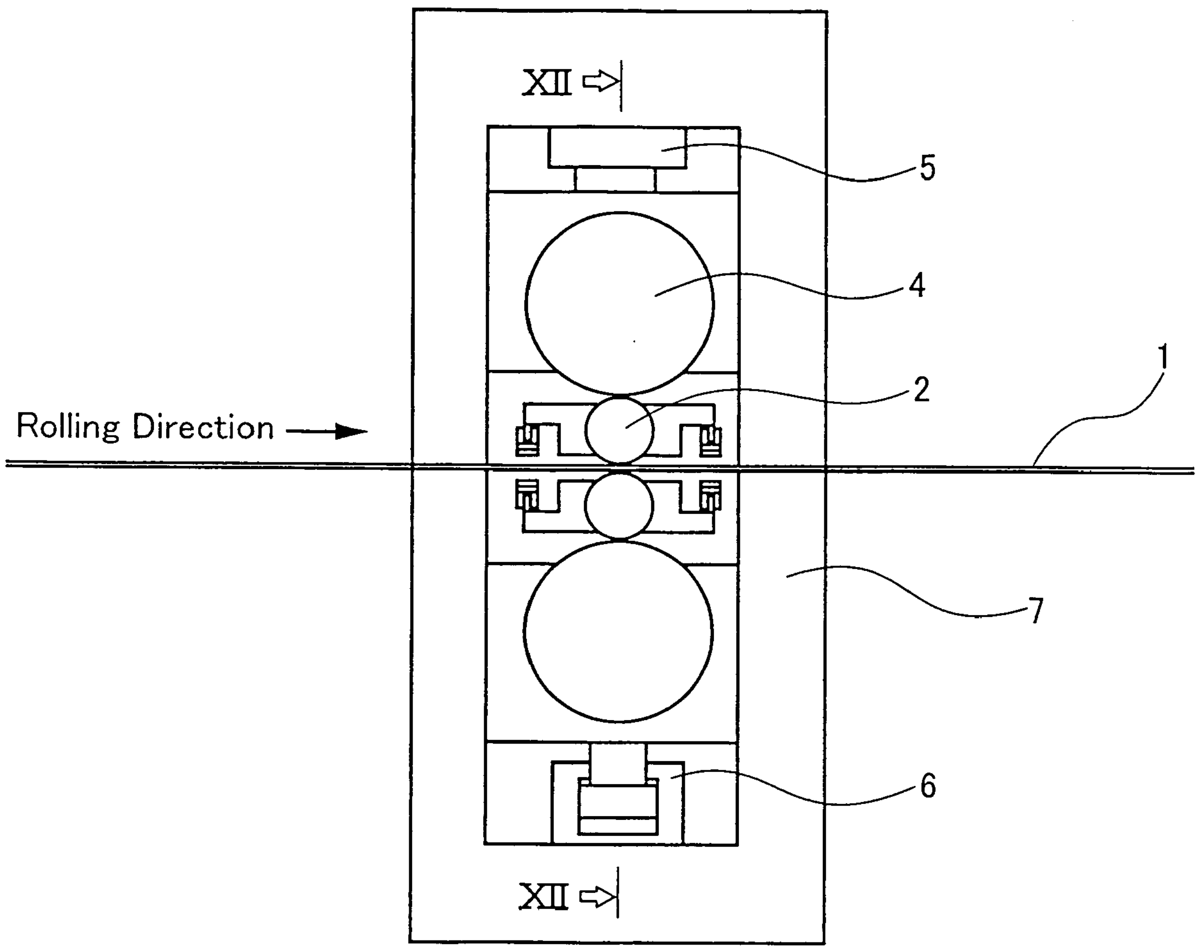


Fig. 12

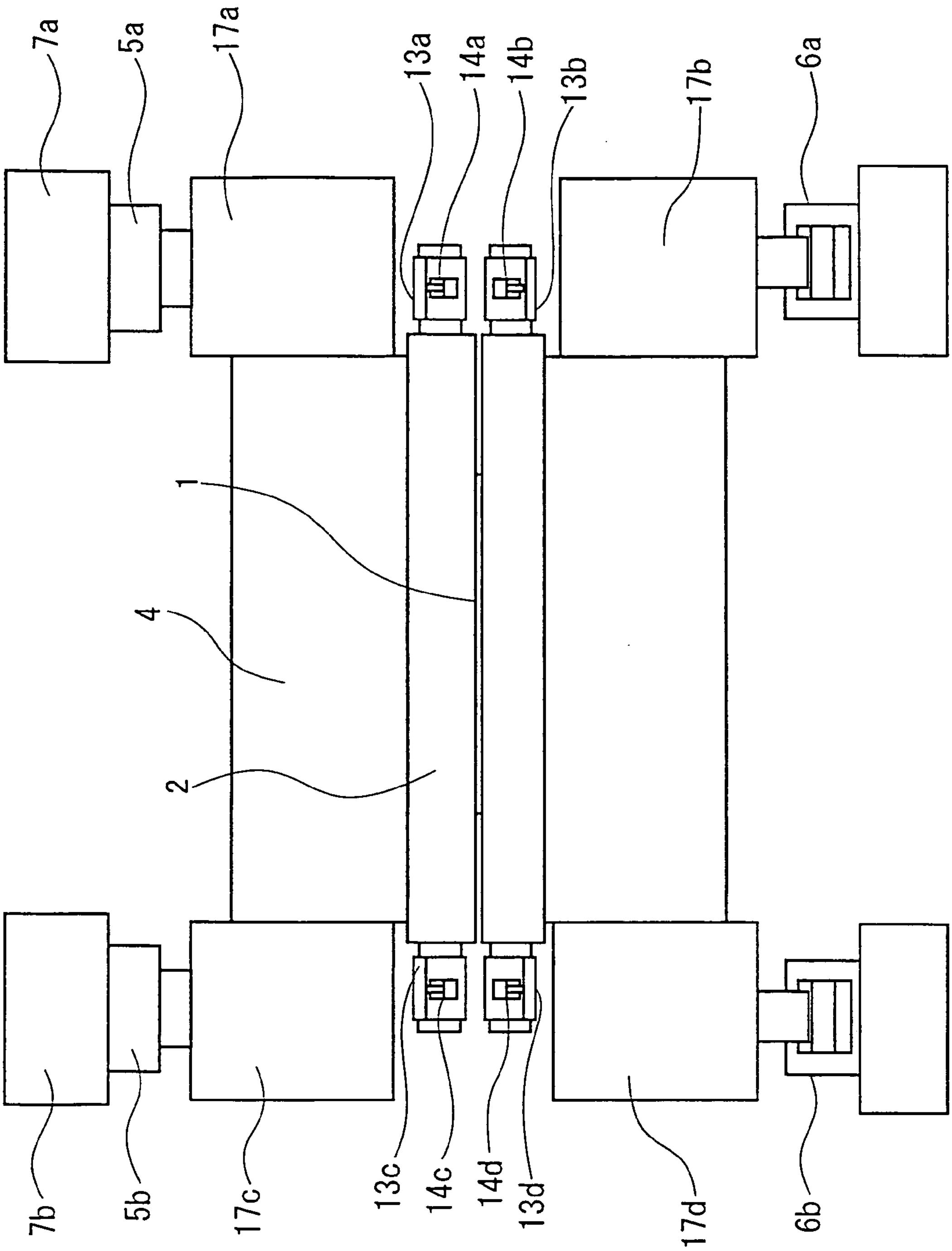

7a
5a
17a
13a
14a
14b
13b
17b
6a
1
4
2
7b
5b
17c
13c
14c
14d
13d
17d
6b

Fig. 13

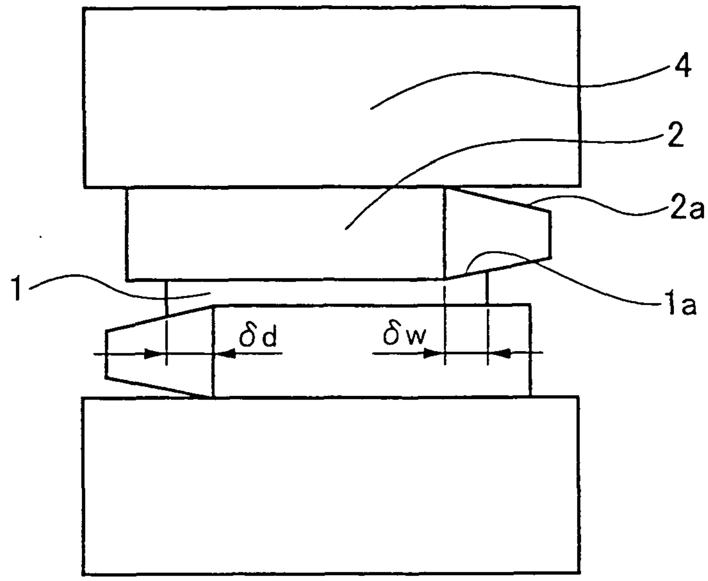
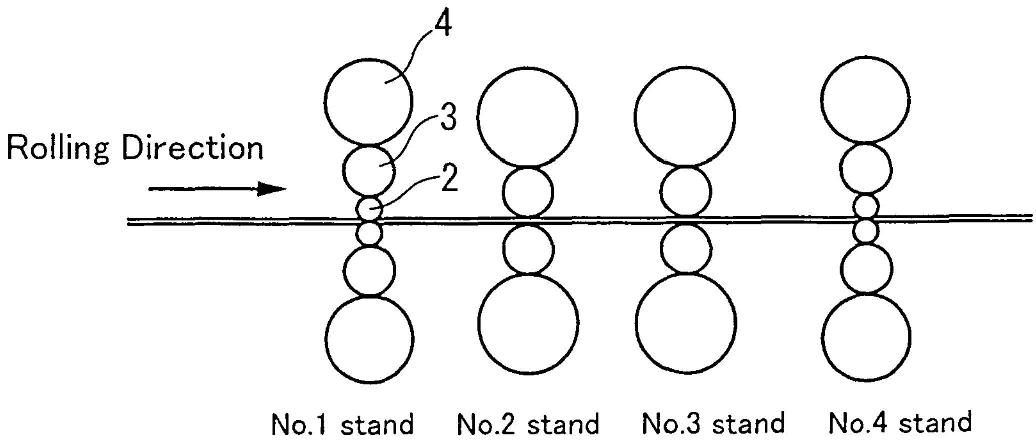

4
2
2a
1
1a
δd
δw

Fig. 14


4
3
2
Rolling Direction
No.1 stand
No.2 stand
No.3 stand
No.4 stand

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EUROPEAN SEARCH REPORT

Application Number
EP 10 00 7529

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 102 08 389 A1 (HITACHI LTD [JP]) 26 June 2003 (2003-06-26) * page 8, paragraph 77; claims 1-7,10; figures 1-5,38 * -----	1-5	INV. B21B27/02
A	EP 0 987 065 A1 (KAWASAKI STEEL CO [JP]) 22 March 2000 (2000-03-22) * page 3, paragraph 11; claims 1,5-6 * -----	1	
			TECHNICAL FIELDS SEARCHED (IPC)
			B21B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	10 November 2010	Forciniti, Marco

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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10-11-2010

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- *Industrial Machinery,* May 1991, 56-60 **[0006]**