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(54) **CONTINUOUS HOT ROLLING FACILITY**

(57) A continuous hot-rolling mill includes an upper rolling unit including a plurality of rolling stands, and a lower rolling unit including a plurality of rolling stands and disposed downstream with respect to the upper rolling unit in a workpiece passing direction in which a workpiece to be rolled is passed. The two or more rolling stands of the lower rolling unit are differential or very-small-diameter rolling stands. Each of the two or more differential or very-small-diameter rolling stands of the lower rolling unit is provided with a drive motor having a capacity greater than that of any one of drive motors included in the rolling stands disposed upstream the differential or very-small-diameter rolling stands. The continuous hot-rolling mill is suitable for producing hot-rolled, fine-grained steel sheets and is excellent in sheet passing abilities for preventing the steel sheet from meandering and for rolling the steel sheet in a desired shape.

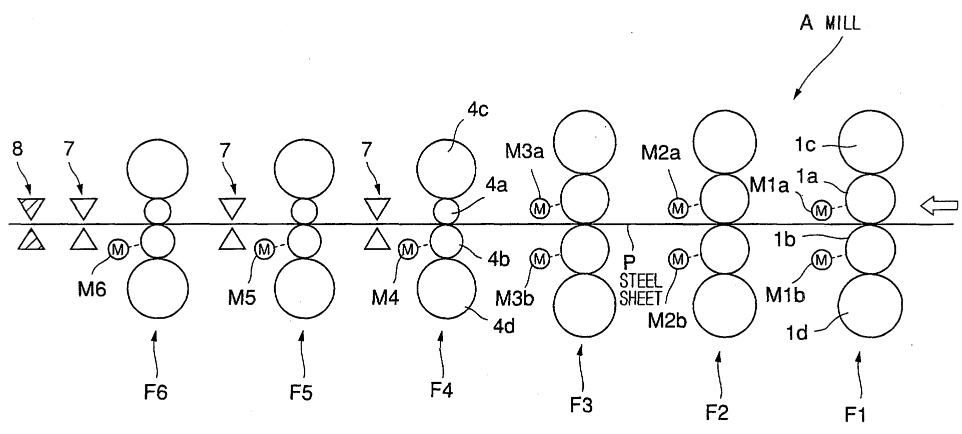

FIG. 1

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Description

TECHNICAL FIELD

[0001] The present invention relates to a continuous hot-rolling mill suitable for manufacturing a hot-rolled fine-grained steel sheet of fine structure mainly of fine ferrite grains.

BACKGROUND ART

[0002] In hot-rolling a thin steel sheet by a continuous hot-rolling mill (finishing mill) formed by arranging five to seven rolling stands in a tandem arrangement, a pass schedule is designed, in most cases, to place a maximum rolling load on the second or the third rolling stand. Such a pass schedule is recommended because a) the workpiece fed to the first rolling stand is thick and the workpiece is not pushed from the upper side into the first rolling stand, and hence the leading end of the thick workpiece cannot be gripped between the rolls if rolling force is excessively high, and b) the workpiece tends to meander and the shape of the workpiece, such as flatness, is deteriorated if an excessively high rolling force is exerted on the workpiece by the lower rolling stands at a lower stage where the workpiece is thin. A pass schedule specifying such a rolling force distribution is mentioned in, for example, Jpn. Pat. No. 2635796 (Figs. 2 and 3).

[0003] The capacity of a drive motor of each of the rolling stands of the conventional continuous hot-rolling mill that is operated on the basis of such a pass schedule is determined by one of the following methods.

i) According to the rolling force distribution specified in the foregoing pass schedule, the output torque of the motors of the lower rolling stands may be smaller than that of the motors of the upper rolling stands, and hence the second rolling stand or the upper rolling stands including the second rolling stand are provided with a motor having a maximum capacity, and the lower rolling stands are provided with a motor having a small capacity.

ii) All the rolling stands are provided with motors having the same capacity and a proper rolling force distribution is designed.

iii) The preceding rolling stand is provided with a motor having a capacity slightly greater than that of the motor of the succeeding rolling stand. The capacities of the motors are thus determined, taking into consideration the increase of rolling speed with the reduction of the thickness of the workpiece and the increase of the rotating speeds of the rolling rolls having smaller diameters of the lower rolling stands, in addition to rolling force distribution.

[0004] The conventional continuous hot-rolling mill has difficulties in producing a hot-rolled, fine-grained steel sheet having fine ferrite structures and high mechanical properties. Hot-rolled, fine-grained steel sheets are manufactured by a high-draft rolling method or a controlled rolling method. Either of those rolling methods requires several rolling stands of a finishing mill to perform high-draft rolling. However, the conventional continuous hot-rolling mill having the rolling stands provided with motors having the capacities explained above has difficulty in carrying out such a rolling method.

[0005] The high-draft rolling method makes fine structure by applying a high rolling force to austenite grains to promote strain-induced transformation from the austenitic (γ) phase to the ferritic (α) phase. The controlled rolling method reduces the grain size of ferrite grains of a low alloy steel containing Nb or Ti by promoting strain-induced transformation from the γ phase to the α phase by the austenite grain recrystallization suppressing effect of Nb or Ti when the low alloy steel is subjected to low-temperature rolling (rolling in the ferrite region) in addition to enhancing the tensile strength of the low alloy steel by the precipitation strengthening effect of Nb or Ti.

[0006] The reason the conventional hot-rolling mill has difficulties in achieving a rolling method to produce fine-grained steel sheets is as follows.

[0007] According to an investigation made by the inventors of the present invention, a rolling method that uses a high rolling force to produce a hot-rolled, fine-grained steel sheet must cause a cumulative strain of 0.9 or above by three lower rolling stands. Strain ε is expressed by:

$$\varepsilon = (h_0 - h_1)/\{(h_0 + h_1)/2\}$$

where h_0 is the thickness of a steel sheet at the entrance of the rolling stand, and h_1 is the thickness of the steel sheet at the exit of the same rolling stand. Cumulative strain is the sum of weighted strains caused by three (or two) lower rolling stands weighted by factors determined taking into consideration the effect of the rolling stands on metal structure and neglecting the effect of upper rolling stands because the effect of the upper rolling stands is insignificant. A cumulative strain ε_c is expressed by:

$$\varepsilon_c = \varepsilon_n + \varepsilon_{n-1}/2 + \varepsilon_{n-2}/4$$

where ε_n is a strain caused by the last rolling stand, ε_{n-1} is a strain caused by the second last rolling stand preceding the last rolling stand, and ε_{n-2} is a strain caused by the third last rolling stand preceding the second last rolling stand.

[0008] To roll a steel sheet at a high draft to cause a cumulative strain of 0.9 or above, each of the three lower rolling stands needs to roll the steel sheet at a draft of about 40% or above (a strain of 0.5 or above). In the conventional hot-rolling mill that operates on the basis of the aforesaid pass schedule, a draft set for each of the three lower rolling stands is only on the order of 30%, and the lower rolling stands are unable to exert a high rolling force for a high draft as high as 40% to achieve a cumulative strain of 0.9 or above when the capacities of the motors are determined as mentioned in i).

[0009] Even if the lower rolling stands are provided with motors each having a relatively large capacity as mentioned in ii and iii), the lower rolling stands do not have a rolling capacity to roll the steel sheet at a high draft by using a high rolling force. Even if the lower rolling stands is provided with a motor having a large capacity, most part of the capacity, in general, is allocated to drive the rolling rolls for rotation at high rotating speeds. Even if the motor of the lower rolling stand has an excess capacity and the lower rolling stand is able to roll the steel sheet at a sufficiently high draft, it is impossible to solve problems relating to the meandering and shape deterioration of thin steel sheets

[0010] Accordingly, it is an object of the present invention to provide a continuous hot-rolling mill suitable for producing a hot-rolled, fine-grained steel sheet, and excellent in sheet passing ability (meandering preventing ability) and preventing the deterioration of the shape of the steel sheet.

DISCLOSURE OF THE INVENTION

[0011] According to the present invention, a continuous hot-rolling mill includes: an upper rolling unit including a plurality of rolling stands; and a lower rolling unit including a plurality of rolling stands and disposed downstream with respect to the upper rolling unit in a workpiece passing direction in which a workpiece to be rolled is passed; wherein the two or more rolling stands of the lower rolling unit are differential or very-small-diameter rolling stands, each of the two or more differential or very-small-diameter rolling stands is provided with a drive motor having a capacity greater than that of any one of drive motors included in the rolling stands disposed upstream with respect to the differential or very-small-diameter rolling stands.

[0012] Preferably, the successive two or more rolling stands of the lower rolling unit including the last rolling stand are the differential or very-small-diameter rolling stands.

[0013] Preferably, the lower rolling unit includes three or more rolling stands, and the two or three rolling stands among the three or more rolling stands are differential or very-small-diameter rolling stands.

[0014] The term "very-small-diameter rolling stand" signifies a rolling stand provided with a pair of work rolls of a diameter below 600 mm. The term "differential rolling stand" signifies a rolling stand provided with a pair of work rolls respectively having different diameters, and the equivalent diameter of the pair of work rolls, namely, the mean of the respective diameters of the pair of work rolls, is below 600 mm. Desirably, the equivalent diameter of the differential rolling stand or the diameter of the rolls of the very-small-diameter rolling stand is 550 mm or below from the viewpoint of function, and, in general, 400 mm or above from the viewpoint of strength.

[0015] In this continuous hot-rolling mill, the drive motors of the two or more differential or very-small-diameter rolling stands of the lower rolling unit have a capacity greater than that of any one of the drive motors of the rolling stands disposed upstream with respect to the differential or very-small-diameter rolling stands. Therefore, the lower rolling unit, which influences metallographic structure greatly, is able to achieve high-draft rolling. Since the lower rolling unit of this tandem rolling mill has the two or more differential or very-small-diameter rolling stands, the tandem rolling mill is able to roll a thin sheet at a high draft without causing the thin sheet to meander or deteriorating the shape of the sheet because the tandem rolling mill of this type is capable of achieving rolling at a high draft (and a large strain) by using a comparatively low rolling force. When the sheet is rolled by a low rolling force, lateral force (thrust) exerted on the sheet is low and hence the sheet is caused to meander scarcely, and the adverse effect of rolling on the shape of the sheet, such as edge drop, can be reduced because the flat deformation of the work rolls is reduced. Since problems relating to the passage and shape of the sheet arise scarcely, the lower rolling unit is able to raise the draft considerably according to the capacity of the drive motor and to roll the sheet at a cumulative strain of 0.9 or above. Thus, the tandem rolling mill is capable of producing a hot-rolled, fine-grained steel sheet having fine structures mainly of fine ferrite grains.

[0016] Preferably, at least one of the rolling stands of either the upper or the lower rolling unit has a CVC function.

[0017] The term "CVC function" signifies a function to change and control roll gap by axially moving a work roll (CVC roll) having an axially continuously changing diameter. The rolling stand having the CVC function is called a CVC rolling stand.

[0018] The lower rolling unit of the continuous hot-rolling mill has a satisfactory control characteristic relating to controlling the passage and shape of the sheet. Since the rolling stand having the CVC function is able to change and control roll gap shape in a wide range, the bending and the crowning of the rolls due to thermal expansion can be prevented to control the shape of the sheet effectively. Accordingly, the passage of the sheet through the lower rolling unit can be stabilized. When the lower rolling unit includes the CVC rolling stand, the passage and shape of the sheet can be directly and finely controlled at a stage near the delivery of a finished sheet. When the upper rolling unit includes the CVC rolling stand, the comparatively thick sheet can be controlled in a wide control range.

[0019] Preferably, the respective capacities of the drive motors of the two or more differential or very-small-diameter rolling stands of the lower rolling unit are determined such that all the drive motors have different capacities, respectively, and the drive motors of the lower rolling stands have capacities not lower than those of the drive motors of the upper rolling stands.

[0020] Preferably, the three rolling stands including the last rolling stand of the lower rolling unit are differential or very-small-diameter rolling stands, the respective capacities of the drive motors of the differential or very-small-diameter rolling stands meet a condition expressed by:

$$P_n > P_{n-1} \geq P_{n-2} \text{ or } P_n \geq P_{n-1} > P_{n-2}$$

where P_n, P_{n-1} and P_{n-2} are the capacities of the drive motors of the last rolling stand, the second last rolling stand precedent to the last rolling stand, and the third last rolling stand precedent to the second last rolling stand, respectively.

[0021] It is effective to increase the strain ε (or the draft) toward the last rolling stand to produce a hot-rolled, fine-grained steel sheet by rolling the steel sheet by the lower rolling unit at high drafts. The influence of the rolling action of the upper rolling stand on the metallographic structure of the sheet is lower than that of the last rolling stand or the rolling stand near the last rolling stand. Therefore it is advantageous to operate the last rolling stand or the rolling stand near the last rolling stand at a high draft to produce a sheet having the same metallographic structure without greatly increasing the average draft of drafts for all the rolling stands. Therefore, the continuous hot-rolling mill is capable of producing a hot-rolled, fine-grained steel sheet efficiently, particularly in respect of equipment cost and energy consumption.

[0022] Preferably, the respective capacities of the drive motors of the two or more differential or very-small-diameter rolling stands of the lower rolling unit are greater by 15% or above than those of the drive motors of the rolling stands disposed upstream with respect to the differential or very-small-diameter rolling stands.

[0023] For example, when the successive three rolling stands including the last rolling stand of the lower rolling unit are differential or very-small-diameter rolling stands, the drive motors of those three rolling stands meet a condition expressed by an inequality:

$$P_n \geq \mathrm{Max}\,(P_1, P_2, ..., P_{n-3}) \times 1.15$$

where P_1, P_2, ..., P_{n-3} are the respective capacities of the drive motors of the first, the second, ... and the (n-3)th rolling stand.

[0024] Preferably, the maximum capacity among the respective capacities of the drive motors of the two or more differential or very-small-diameter rolling stands of the lower rolling unit is greater by 30% or above than those of the drive motors of the rolling stands disposed upstream with respect to the differential or very-small-diameter rolling stands.

[0025] For example, when the three successive rolling stands of the lower rolling unit are differential or very-small-diameter rolling stands, the drive motors of the rolling stands meet a condition expressed by:

$$\mathrm{Max}\,(P_{n-2}, P_{n-1}, P_n) \geq \mathrm{Max}\,(P_1, P_2, ..., P_{n-3}) \times 1.3$$

where P_n, P_{n-1} and P_{n-2} are the respective capacities of the drive motors of the three successive rolling stands, and P_1, P_2, ..., P_{n-3} are the respective capacities of the drive motors of the first, the second, ..., and the (n-3)th rolling stand.

[0026] As mentioned above, in view of the influence of rolling action on the metallographic structure, the upper rolling stands of the continuous hot-rolling mill do not need to roll the steel sheet at particularly high draft in producing a hot-rolled, fine-grained steel sheet. On the other hand, it is preferable that the lower rolling stands including the last rolling stand roll the steel sheet at high drafts to increase the cumulative strain to 0.9 or above. Therefore, the continuous hot-rolling mill including the two or more lower rolling stands, namely, the differential or very-small-diameter rolling stands, provided with the drive motors having the capacities considerably larger than those of the motors of the upper rolling stands is a reasonable, viable continuous hot-rolling mill capable of smoothly producing a hot-rolled, fine-grained steel sheet. Since the rolling stands of the upper rolling unit that roll the steel sheet at low drafts are provided with the drive motors having capacities considerably smaller than those of the drive motors of the rolling stands of the lower rolling unit, the continuous hot-rolling mill is economically advantageous. It is particularly advantageous in equipment cost and energy consumption to provide the last rolling stand with a motor having the maximum capacity for the aforesaid reasons.

[0027] Preferably, water-curtain cooling means are disposed at the exits of the two or more differential or very-small-diameter rolling stands of the lower rolling unit to cool the rolled workpiece.

[0028] Each of the water-curtain cooling means is capable of pouring a cooling water at a high pouring rate in water-curtains of laminar or substantially laminar water streams from above and from below the sheet toward the sheet such that the upper and the lower surface of the sheet are wetted entirely with the cooling water for cooling.

[0029] In producing a hot-rolled, fine-grained steel sheet by the continuous hot-rolling mill, it is desirable to cool the steel sheet strongly at the rolling stands that roll the steel sheet at high drafts because the steel sheet is often heated at a high temperature not suitable for the high-draft rolling method or the controlled rolling method by heat generated by rolling when the steel sheet is rolled at a high draft. The rolling speed needs to be reduced and the commercial production of hot-rolled, fine-grained steel sheets could be impossible if the steel sheets are not cooled sufficiently effectively.

[0030] The water-curtain cooling means cools the steel sheet effectively by pouring water in water-curtains at a high pouring rate to suppress the rise of the temperature of the sheet effectively when the sheet is rolled at a high draft. Even if the rolling speed is increased, the sheet can be maintained at a temperature in a proper temperature range. The proper temperature range is between the Ar_3 transformation temperature and a temperature equal to the Ar_3 transformation temperature plus 50°C for the high-draft rolling method and between 700°C and 800°C for the controlled rolling method.

[0031] The water-curtain cooling means are disposed not only at the exit of the last rolling stand but also at the respective exits of the plurality of rolling stands of the lower rolling unit. Thus, heat generated in the steel sheet by rolling at the rolling stands including the last rolling stand is removed effectively to maintain the steel sheet at a proper temperature, and the sheet is cooled strongly immediately after rolling by the last rolling stand to stop the growth of grains of the fine structure. Since the water-curtain cooling means pour cooling water over the entire width of the rolled steel sheet, the rolled steel sheet can be uniformly cooled.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032]

Fig. 1 is a typical side elevation of a continuous hot-rolling mill A in a preferred embodiment according to the present invention;

Figs. 2A, 2B and 2C are typical views of assistance in explaining the CVC function of a rolling stand F1 included in an upper rolling unit in the continuous hot-rolling mill A shown in Fig. 1;

Fig. 3 is a side elevation of rolling stands F4 to F6 included in a lower rolling unit in the continuous hot-rolling mill A shown in Fig. 1;

Fig. 4 including (a) and (b) shows sections of upper and lower surface layers, respectively, of a hot-rolled steel sheet; and

Fig. 5 is a graph showing necessary torques for drive motors included in the rolling stands F1 to F6 calculated on the basis of a pass schedule, and expectedly suitable output torques of the drive motors corresponding to the necessary torques, respectively.

BEST MODE FOR CARRYING OUT THE INVENTION

[0033] A continuous hot-rolling mill A shown in Fig. 1 is a finish-rolling mill. A heating furnace and a roughing rolling mill, which are not shown, are disposed upstream with respect to the continuous hot-rolling mill A. A runout table and a coiler, which are not shown, are disposed downstream with respect to the continuous hot-rolling mill A. The continuous hot-rolling mill A includes six rolling stands F1 to F6 each provided with rolling rolls. The rolling stands F1 to F6 are arranged in a tandem arrangement. The continuous hot-rolling mill A rolls a rough-rolled steel sheet P continuously to produce a hot-rolled steel sheet of a thickness in the range of about 1 to about 6 mm. The continuous hot-rolling mill A is designed to carry out both an ordinary rolling process for producing general steel sheets and a fine-graining rolling process for producing hot-rolled, fine-grained steel sheets having a fine ferrite structure. The construction of the continuous hot-rolling mill A will be described.

[0034] The three upper rolling stands F1, F2 and F3, namely, rolling stands included in an upper rolling unit, are CVC rolling stands. The rolling stands F1, F2 and F3 are arranged in a tandem arrangement. As shown in Fig. 1, the first rolling stand F1, i.e., the uppermost rolling stand, is a four-high rolling mill having two work rolls 1a and 1b, and two backup rolls 1c and 1d. As shown in Fig. 2A, the work rolls 1a and 1b are crowned (CVC, i.e., continuous variable crown). The work rolls 1a and 1b can be simultaneously axially moved in opposite directions, respectively, as shown in Figs. 2B and 2C for the adjustment of the positional relation between the work rolls 1a and 1b to adjust the gap between the working rolls 1a and 1b. The respective diameters of the work rolls 1a and 1b are 700 mm. The work rolls 1a and 1b can move axially from their reference positions in the range of ±100 mm. The second rolling stand F2 and the third rolling stand F3 of the upper rolling unit, namely, CVC rolling stands, are the same in construction and function as the first rolling stand F1.

[0035] The upper rolling unit includes the CVC rolling stands F1, F2 and F3 to crown (to shape) the steel sheet P properly. The lower rolling stands F4, F5 and F6 included in a lower rolling unit are differential rolling mills. Thermal crowning is liable to occur due to working heat generated by fine-graining rolling. Therefore, the crown of the steel sheet P is corrected by the CVC rolling stands F1, F2 and F3 of the upper rolling unit to reduce center buckle and such in the steel sheet P.

[0036] As shown typically in Fig. 1, drive motors M1a and M1b (generally denoted by M1") are connected to the work rolls 1a and 1b of the CVC rolling stand F1, respectively, drive motors M2a and M2b (M2) are connected to the work rolls 1a and 1b of the CVC rolling stand F2, respectively, and drive motors M3a and M3b (M3) are connected to the work rolls 1a and 1b of the CVC rolling stand F3, respectively. The drive motors M1, M2 and M3 are ac motors provided respectively with variable-speed controllers. The motors M1, M2 and M3 are connected through reduction gears, not shown, and universal joints to the work rolls 1a and 1b of the rolling stands F1, F2 and F3, respectively.

[0037] The three lower rolling stands F4, F5 and F6, namely, the differential rolling mills, of the lower rolling unit are arranged in a tandem arrangement. The six rolling stands, namely, the rolling stands F1, F2 and F3 (the CVC rolling mills) and the rolling stands F4, F5 and F6 are arranged at equal intervals of 5.5 m. As shown in Fig. 1, the fourth rolling stand F4, namely, the differential rolling stand, is a four-high rolling mill provided with two work rolls 4a and 4b and two backup rolls 4c and 4d. The work rolls 4a and 4b have different diameters, respectively. The upper work roll 4a is a small work roll, and the lower work roll 4b is a large work roll. Only the large lower work roll 4b is driven by a drive motor M4 (ac motor with a variable-speed controller). The drive motor M4 is connected through a reduction gear, not shown, and a universal joint to the lower work roll 4b. The small upper work roll 4a is a free roll. Benders, not shown, are combined with the work rolls 4a and 4b for bending the work rolls 4a and 4b. The work rolls 4a and 4b have the CVC function, and can move axially in opposite directions from their reference positions in the range of ±100 mm. The diameters of the upper work roll 4a and the lower work roll 4b are 480 mm and 600 mm, respectively. Equivalent roll diameter equal to the mean of the respective diameters of the work rolls 4a and 4b is as small as 540 mm. The other differential rolling stands F5 and F6 are the same in construction and function as the differential rolling stand F4. Drive motors M5 and M6 are connected to the lower work rolls 4b of the rolling stands F5 and F6, respectively.

[0038] Thus, the three lower rolling stands F4, F5 and F6 have the small equivalent roll diameters and only the lower work rolls 4b are driven to exert a shearing force to the steel sheet P. Therefore, the lower rolling stands F4, F5 and f6 are able to roll the steel sheet P at a draft of, for example, 50% by a comparatively low rolling force. Thus, the lower rolling stands F4, F5 and F6 are capable of achieving fine-graining, high-draft rolling by a low rolling force, and of avoiding problems attributable to edge drop and the flat deformation of the work rolls because the rolling stands F4, F5 and F6 need to exert a low rolling force.

[0039] The steel sheet P needs to be maintained at temperatures in a proper temperature range by sufficient cooling to achieve the continuous fine-graining rolling. Water-curtain cooling devices 7 (reference numbers 7A to 7H shown in Fig. 3) are disposed behind the lower rolling stands F4, F5 and F6, respectively, as shown in Fig. 1, or water-curtain cooling devices 7A to 7H are disposed behind the lower rolling stands F4, F5 and F6, i.e., on the downstream side of the lower rolling stands F4, F5 and F6, and in front of the lower rolling stands F4, F5 and F6. i.e., on the upstream side of the lower rolling stands F4, F5 and F6, as shown in Fig. 3. Each of the water-curtain cooling devices 7 has upper and lower headers disposed above or below, respectively, of the steel sheet P, and is capable of pouring cooling water of an ordinary temperature on the surfaces of the steel sheet P at a high pouring rate in water-curtains (water-curtains f in Fig. 3), namely, laminar water streams, over the entire width of the steel sheet P. The thickness of the water-curtains is 10 mm or above, desirably, about 16 mm, from the viewpoint of the cooling effect of the water-curtains. The pouring rate at which each of the curtain wall cooling devices 7 pours cooling water on a unit width of 1m of the steel sheet P is adjustable in the range of 100 to 500 m^3/h. The pouring rate is adjusted such that the steel sheet P is cooled at a cooling rate of 20°C /s or above. When the steel sheet P is rolled by the high-draft rolling method, the cooling water is poured on the steel sheet P at a pouring rate for unit width of 350 m^3/h, and the product of the thickness and the speed of the steel sheet P is 1200 mm·mpm, the temperature of the steel sheet P drops at a temperature drop rate in the range of 60 to 80°C/s (about 40°C/sec when the steel sheet P is heated by heat generated by rolling).

[0040] As shown in Fig. 3, the cooling devices 7 are disposed above and below the steel sheet. The cooling devices 7A, 7B, 7D, 7E and 7B are disposed above the steel sheet P near the exit of the rolling stand 4F, near the entrance and the exit of the rolling stand F5, and near the entrance and the exit of the rolling stand F6, respectively. The cooling devices 7C, 7F and 7H are disposed below the steel sheet P near the exits of the rolling stands F4, F5 and F6, respectively. The cooling device 7H is attached to the frame of a roller table T disposed downstream with respect to the sixth rolling stand F6, and the other cooling devices 7A to 7G are attached to the housings H of the rolling stands F4, F5 and F6.

[0041] The cooling devices 7 disposed near the exits of the three lower rolling stands F4, F5 and F6 controls the excessive rise of the temperature of the steel sheet P rolled by the rolling stands F4, F5 and F6 by the high-draft rolling method that generates a large amount of heat or the controlled rolling method to maintain the temperature of the steel sheet P in the proper temperature range and stops the growth of grains of the fine structure after rolling. The steel sheet P is cooled with cooling water to prevent the growth of grains at the runout table, not shown, disposed downstream with respect to the continuous hot-rolling mill A.

[0042] The continuous hot-rolling mill A shown in Fig. 1 includes a spray device 8 at a distance in the range of several hundred millimeters and one meter from the water-curtain cooling devices 7, namely, the water-curtain cooling devices 7G and 7H disposed near the exit of the last rolling stand F6. The spray device 8 jets water obliquely forward by pressure onto the surfaces of the steel sheet P to remove the cooling water poured by the cooling devices 7G and 7H on the steel sheet P and remaining on the steel sheet P. Thus, the cooling water remaining on the steel sheet P can be efficiently removed and, consequently, instruments including a thermometer, not shown, disposed downstream with respect to the spray device 8 are able to measure data about the steel sheet P accurately.

[0043] The continuous hot-rolling mill A is capable of producing a hot-rolled, fine-grained steel sheet at a sufficiently high rolling speed to ensure proper productivity. The lower differential rolling stands F4, F5 and F6 provided with the small-diameter rolls, which influence greatly the metallographic structure of the rolled steel sheet, roll the steel sheet P at high drafts by the high-draft rolling method or the controlled rolling method, maintaining the temperature of the steel sheet P in the proper temperature range by means of the water-curtain cooling devices 7. The rolling stands F4, F5 and F6 are capable of preventing edge drop and the flat deformation of the work rolls, and the rolling stands F1 to F6 having the CVC function are capable of controlling crowning. Consequently, the meandering of the steel sheet P and the deterioration of the shape of the steel sheet P in the lower rolling stands where the steel sheet P are thin can be prevented, so that fine-graining rolling can be successfully achieved.

[0044] The drive motors of the lower rolling stands, particularly, the drive motor M6 of the lowermost rolling stand, such as the rolling stand F6, or the drive motor M5 of the rolling stand adjacent to the last rolling stand, such as the rolling stand F5, must have a sufficient capacity (power (kW)) to achieve the high-draft rolling by the rolling stands of the lower rolling unit. When the steel sheet P is rolled by high-draft rolling, a high rolling force per unit width needs to be applied to the steel sheet P, a high torque, the magnitude of which is dependent on the thickness of the steel sheet P, is needed to rotate the work rolls 4a and 4b, and rolling speed increases as the thickness of the steel sheet P decreases. Consequently, high-draft rolling, as compared with ordinary rolling, needs high power. If the drive motor has an insufficient capacity and is unable to produce a sufficient torque for rotating the work roll, it is difficult to achieve fine-graining rolling with the steel sheet P if the steel sheet P has a width greater than a threshold width. Fine-graining rolling at a sufficiently high rolling speed cannot be achieved when the power of the drive motor is insufficient even if a sufficient torque can be applied to the work roll.

[0045] It is meaningless to operate the upper rolling stands F1, F2 and F3 of the upper rolling unit for high-draft rolling because the influence of the rolling operation of the upper rolling stands F1, F2 and F3 on the metallographic structure of the steel sheet P is weak. Therefore, the upper rolling stands F1, F2 and F3 are not operated for high-draft rolling even if the continuous hot-rolling mill is operated for fine-graining rolling, and hence the capacities of the drive motors of the upper rolling stands F1, F2 and F3 do not need to be as high as those of the drive motors of the lower rolling stands. Thus, motor capacities P1, P2 and P3 of the upper rolling stands F1, F2 and F3, namely, the sum of the capacities of the two drive motors M1a and M1b (the motors M1) of the rolling stand F1, the sum of the capacities of the two drive motors M2a and M2b (the motors M2) of the rolling stand F2, and the sum of the capacities of the two drive motors M3a and M3b (the motors M3) of the rolling stand F3, may be smaller than the respective capacities P_4, P_5 and P_6 of the drive motors M4, M5 and M6 of the lower rolling mills F4, F5 and F6.

[0046] On the basis of facts that it is advantageous to operate the lower rolling stand for fine-graining rolling at a higher draft in respect of metallographic structure and energy efficiency, and since the lower rolling stands need higher power capacities as specified by a pass schedule shown in Table 3 of an example described hereunder, it is preferable that the respective capacities of the drive motors of the rolling stands meet the following conditions. The respective capacities P_4, P_5 and P_6 of the drive motors M4, M5 and M6 of the three lower rolling stands need to meet a condition shown in Table 4, which will be described hereunder, expressed by:

$$P_4 < P_5 \leq P_6,\ P_4 \leq P_5 < P_6,\ \text{or}\ P_4 < P_5 < P_6,$$

$$P_6 \geq \mathrm{Max}(P_1, P_2, P_3) \times 1.3$$

[0047] Expression: $P_6 \geq Max(P_1, P_2, P_3) \times 1.3$ signifies that the capacity P_6 of the drive motor M6 is not smaller than 1.3 times in comparison to the largest one of the capacities P_1, P_2, P_3 of the drive motors M1, M2 and M3 of the upper rolling stands F1, F2 and F3. If it is desired to benefit equipment cost and handling by reducing the number of the types of the drive motors, the drive motors may have capacities meeting the following conditions.

$$P_4 < P_5 \leq P_6,\ P_4 \leq P_5 \leq P_6,\ \text{or}\ P_4 < P_5 < P_6,$$

$$P_4 \geq Max(P_1, P_2, P_3) \times 1.15$$

[0048] Expression: $P_4 \geq Max(P_1, P_2, P_3) \times 1.15$ signifies that the capacities of the drive motors of the lower rolling stands are not smaller than 1.15 times in comparison to the largest one of the capacities P_1, P_2, P_3 of the drive motors M1, M2 and M3 of the upper rolling stands F1, F2 and F3.

EXAMPLES

[0049] A pass schedule for the continuous hot-rolling mill A, and the distribution of the respective capacities of the drive motors of the rolling stands F1 to F6 will be described by way of example.

[0050] The continuous hot-rolling mill A is operated to produce a steel sheet of 2.3 mm in thickness and 1200 mm in width by rolling a steel workpiece containing 0.16% C, 0.22% Si and 0.82% Mn (not containing other substances in significant content). The continuous hot-rolling mill A operates at a rolling speed at which general hot strip mills operate. For example, the continuous hot-rolling mill A operates at a rolling speed in the range of 7 to 9 m/s.

[0051] Table 1 shows a general pass schedule for ordinary rolling for producing general-purpose steel sheets which are not fine-grained steel sheets. It may be proper to provide the rolling stands F1 to F6 with drive motors having capacities shown in Table 2 (which are distributed in a conventional capacity distribution) to carry out a rolling operation specified by the pass schedule shown in Table 1. In Table 1 (and Table 3 mentioned hereunder), values of "rolling torque" and "rolling power" are those for the work rolls 1a, 1b, 4a and 4b, and "rough bar" is a workpiece rolled by a roughening rolling mill, and "F1" to "F6" denote the first to the sixth rolling stands. In Table 2 (and Table 4 mentioned hereunder), values in the line "Max. torque" are torques applied to the work rolls 1a and 1b or the work rolls 4a and 4b of each rolling stand by the drive motor. Capacities of the drive motors shown in Table 2 include a considerable extra capacity because, in some cases, the rolling stands F2 to F6 operate at drafts and at rolling speeds higher than those shown in Table 1, and need more rolling power than that shown in Table 1 to produce hot-rolled steel sheets of thicknesses of 2.0 mm or below.

Table 1

Pass Schedule for Ordinary Rolling (Width of sheet: 1200 mm)							
	Rough bar	F1	F2	F3	F4	F5	F6
Thickness	36.0	18.7	10.3	6.4	4.0	2.9	2.3
Rolling force (ton)		2,097	1,611	1,348	1,157	1,054	684
Rolling torque (ton·m)		145.7	71.8	40.9	28.2	17.0	6.9
Rolling power (kW)		1,698	1,244	1,128	1,731	1,693	1,382

Table 2

Drive Motors for Conventional Rolling Mill							
		F1	F2	F3	F4	F5	F6
Capacity (kW)		8,400	10,500	10,500	8,400	8,400	6,650
Max. torque (ton·m)		225	221	138	61	41	28

[0052] When producing a fine-grained steel sheets having fine structure mainly of fine ferrite grains, which are not general-purpose hot-rolled steel sheets, the continuous hot-rolling mill A operates, for example, according to a pass schedule shown in Table 3 specifying high drafts for the three lower rolling stands F4, F5 and F6. According to the pass schedule shown in Table 3, the last rolling stand F6 and the second last rolling stand F5 roll the steel sheet at drafts of 40% or above (strains of 0.5 or above). The continuous hot-rolling mill A cools the rolled steel sheet P by the water-curtain cooling devices 7 (7A to 7H) to maintain the steel sheet P at a proper temperature during rolling so that a fine-grained hot-rolled steel sheet having a fine ferrite structure as shown in Fig. 4 including (a) and (b) are produced.

Table 3

Pass Schedule for Fine-graining Rolling (Width of sheet: 1200 mm)							
	Rough bar	F1	F2	F3	F4	F5	F6
Thickness	40.0	28.8	19.7	12.3	7.5	4.5	2.3
Rolling force (ton)		2,053	2,160	2,515	1,995	2,081	2,158
Rolling torque (ton·m)		116.4	105.7	109.3	71.6	53.7	48.4
Rolling power (kW)		1,356	1,832	3,012	4,396	5,365	9,640

[0053] Necessary rolling torques for the lower rolling stands specified by the pass schedule shown in Table 3 are high as compared with the corresponding necessary rolling torques specified by the pass schedule shown in Table 1, and, as shown in Fig. 5, are greater than the torques of the drive motors of the lower rolling stands F4, F5 and F6 shown in Table 2 (i.e., torques indicated by solid circles in Fig. 5). The necessary rolling torques for the lower rolling stands exceed those shown in Table 1 because high rolling forces are necessary for high draft rolling. Since rolling speeds for the last rolling stand and the second rolling stand increase sharply in inverse proportion to the sharp reduction of the thickness of the steel sheet due to high-draft rolling. Consequently, the rolling stands F5 and F6 need rolling power far higher than that needed by the upper rolling stands.

[0054] Thus, if the capacities of the drive motors are distributed in a capacity distribution shown in Table 2 that is considered to be suitable for ordinary rolling, the output torques and capacities (power capacities) of the drive motors M4, M5 and M6 of the rolling stands F4, F5 and F6 are insufficient. Therefore, it is proper that the drive motors M4, M5 and M6 of the lower rolling stands have large capacities as shown in Table 4 to ensure that continuous hot-rolling mill A provided with the drive motors M1 to M6 is able to carry out fine-graining rolling satisfactorily.

Table 4

Drive Motors for Fine-graining Rolling							
		F1	F2	F3	F4	F5	F6
Capacity (kW)		8,400	10,500	10,500	11,000	13,000	14,000
Max. torque (ton·m)		225	221	138	80	63	58

[0055] Tables 3 and 4 show capacities (power) and toques generated in the drive motors M1 to M6 of the rolling stands F1 to F6 during the rolling operation, i.e., during the rolling of the steel sheet P. Since the length of the steel sheet P is not indefinite and the rolling operation is not continued without interruption, the output capacities shown in Tables 3 and 4 are not necessarily the rated output capacities of the drive motors M1 to M6. Therefore, it is preferable to determined proper rated output capacities with reference to the output capacities shown in Tables 3 and 4, the duration of rolling and the frequency of the rolling operation by a root means square method or the like, and to select drive motors M1 to M6 having the proper rated output capacities.

INDUSTRIAL APPLICABILITY

[0056] The present invention is applicable to a continuous hot-rolling mill for manufacturing a hot-rolled, fine-grained steel sheet of fine structure mainly of fine ferrite grains.

Claims

1. A continuous hot-rolling mill comprising:

an upper rolling unit including a plurality of rolling stands; and a lower rolling unit including a plurality of rolling stands and disposed downstream with respect to the upper rolling unit in a workpiece passing direction in which a workpiece to be rolled is passed;

wherein two or more rolling stands of the lower rolling unit are differential or very-small-diameter rolling stands,

each of the two or more differential or very-small-diameter rolling stands of the lower rolling unit is provided with a drive motor having a capacity greater than a capacity of any one of drive motors included in the rolling stands disposed upstream with respect to the differential or very-small-diameter rolling stands.

2. The continuous hot-rolling mill according to claim 1, wherein successive two or more rolling stands of the lower rolling unit including a last rolling stand are the differential or very-small-diameter rolling stands.

3. The continuous hot-rolling mill according to claim 1 or 2, wherein the lower rolling unit includes three or more rolling stands, and two or three rolling stands among the three or more rolling stands of the lower rolling unit are the differential or very-small-diameter rolling stands.

4. The continuous hot-rolling mill according to any one of claims 1 to 3, wherein at least one of the rolling stands of either the upper or the lower rolling unit has a CVC function.

5. The continuous hot-rolling mill according to any one of claims 1 to 4, wherein the drive motors of the two or more differential or very-small-diameter rolling stands of the lower rolling unit have different capacities, respectively, and drive motors of lower rolling stands have capacities not lower than capacities of drive motors of upper rolling stands.

6. The continuous hot-rolling mill according to claim 5, wherein three rolling stands including a last rolling stand of the lower rolling unit are differential or very-small-diameter rolling stands,

respective capacities of the drive motors of the differential or very-small-diameter rolling stands meet a condition expressed by:

$$P_n > P_{n-1} \geq P_{n-2} \text{ or } P_n \geq P_{n-1} > P_{n-2}$$

where P_n, P_{n-1} and P_{n-2} are capacities of the drive motors of the last rolling stand, a second last rolling stand precedent to the last rolling stand, and a third last rolling stand precedent to the second last rolling stand, respectively.

7. The continuous hot-rolling mill according to claim 5 or 6, wherein respective capacities of the drive motors of the two or more differential or very-small-diameter rolling stands of the lower rolling unit are greater by 15% or above than any one of capacities of the drive motors of the rolling stands disposed upstream with respect to the differential or very-small-diameter rolling stands.

8. The continuous hot-rolling mill according to any one of claims 1 to 7, wherein a maximum capacity among respective capacities of the drive motors of the two or more differential or very-small-diameter rolling stands of the lower rolling unit is greater by 30% or above than any one of capacities of the drive motors of the rolling stands disposed upstream with respect to the differential or very-small-diameter rolling stands.

9. The continuous hot-rolling mill according to any one of claims 1 to 8, wherein water-curtain cooling means are disposed at respective exits of the two or more differential or very-small-diameter rolling stands of the lower rolling unit in order to cool a rolled workpiece.

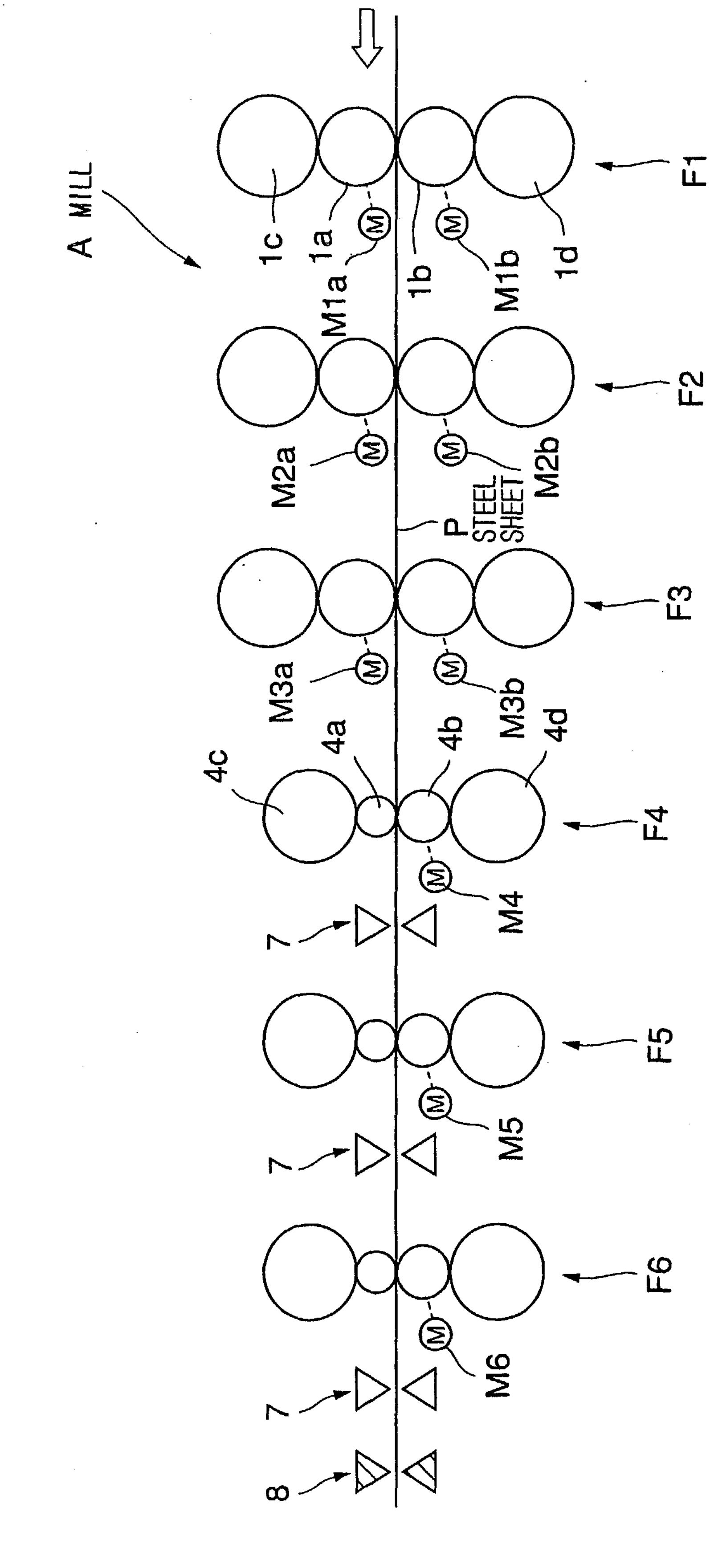
A MILL
1c
1a
M1a
1b
M1b
1d
F1
F2
M2a
M2b
P
STEEL SHEET
F3
M3a
M3b
4c
4a
4b
4d
F4
M4
7
F5
M5
7
F6
M6
7
8

FIG. 1

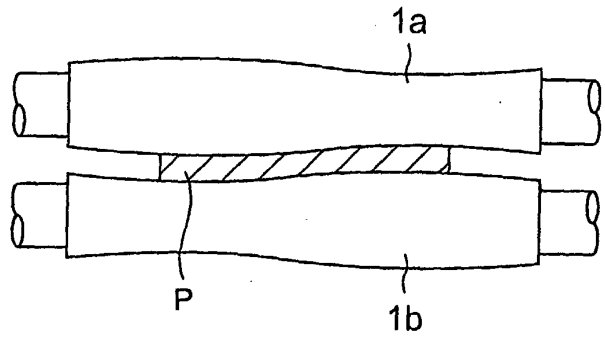

FIG.2A

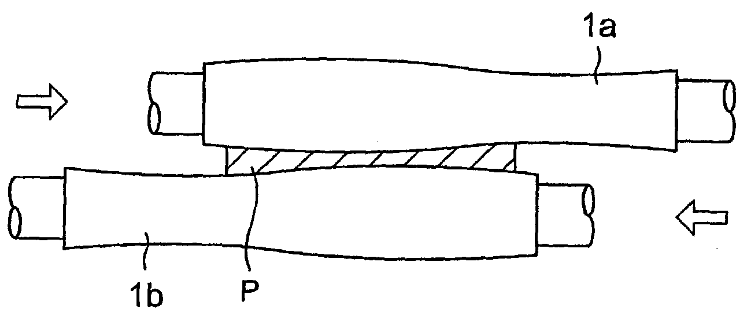

FIG.2B

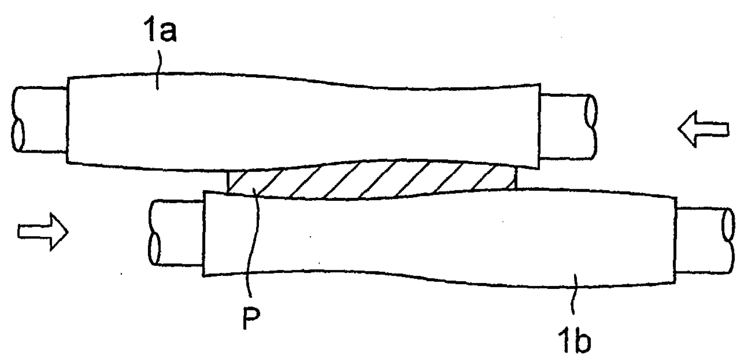

FIG.2C

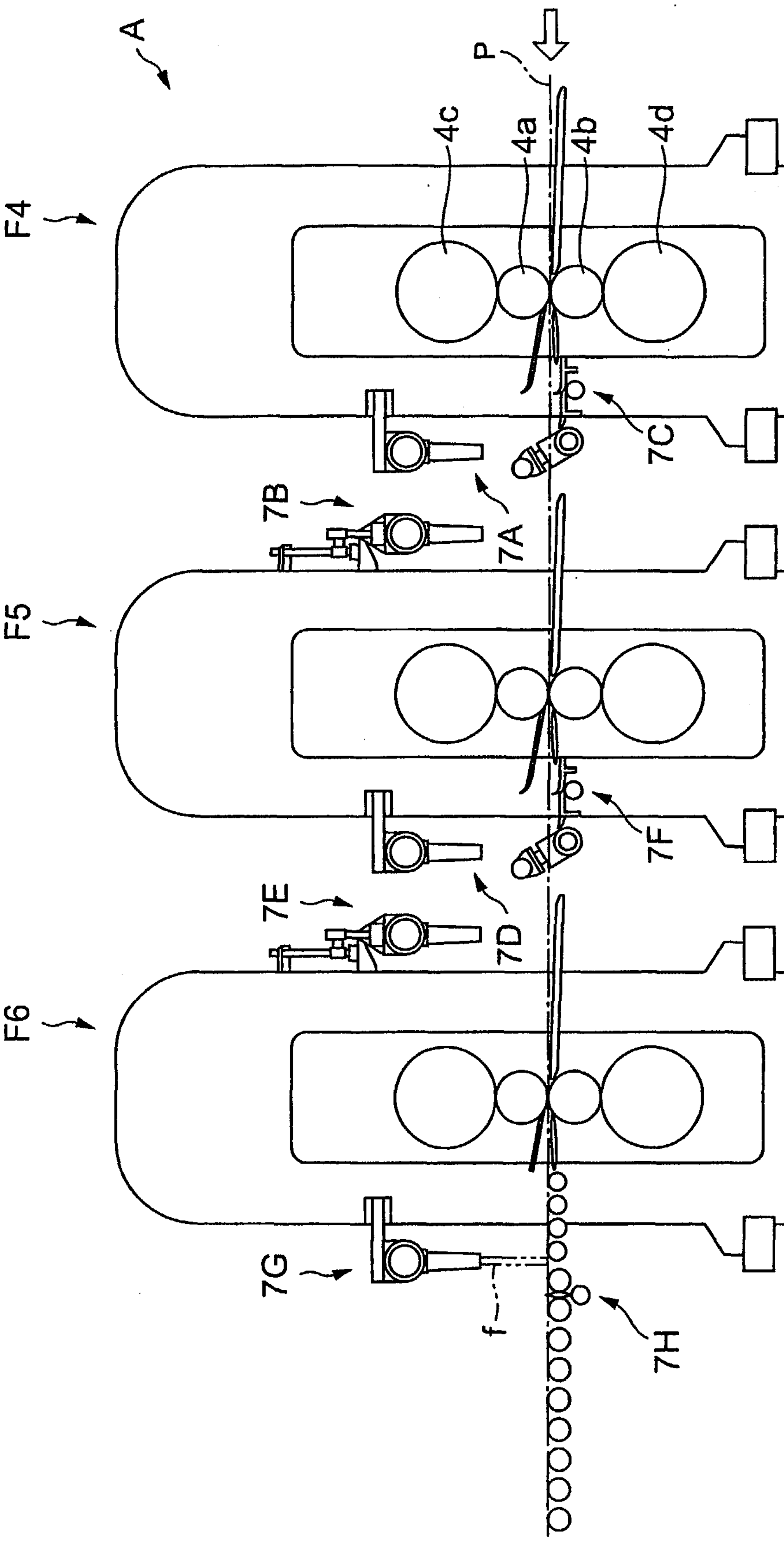

FIG. 3

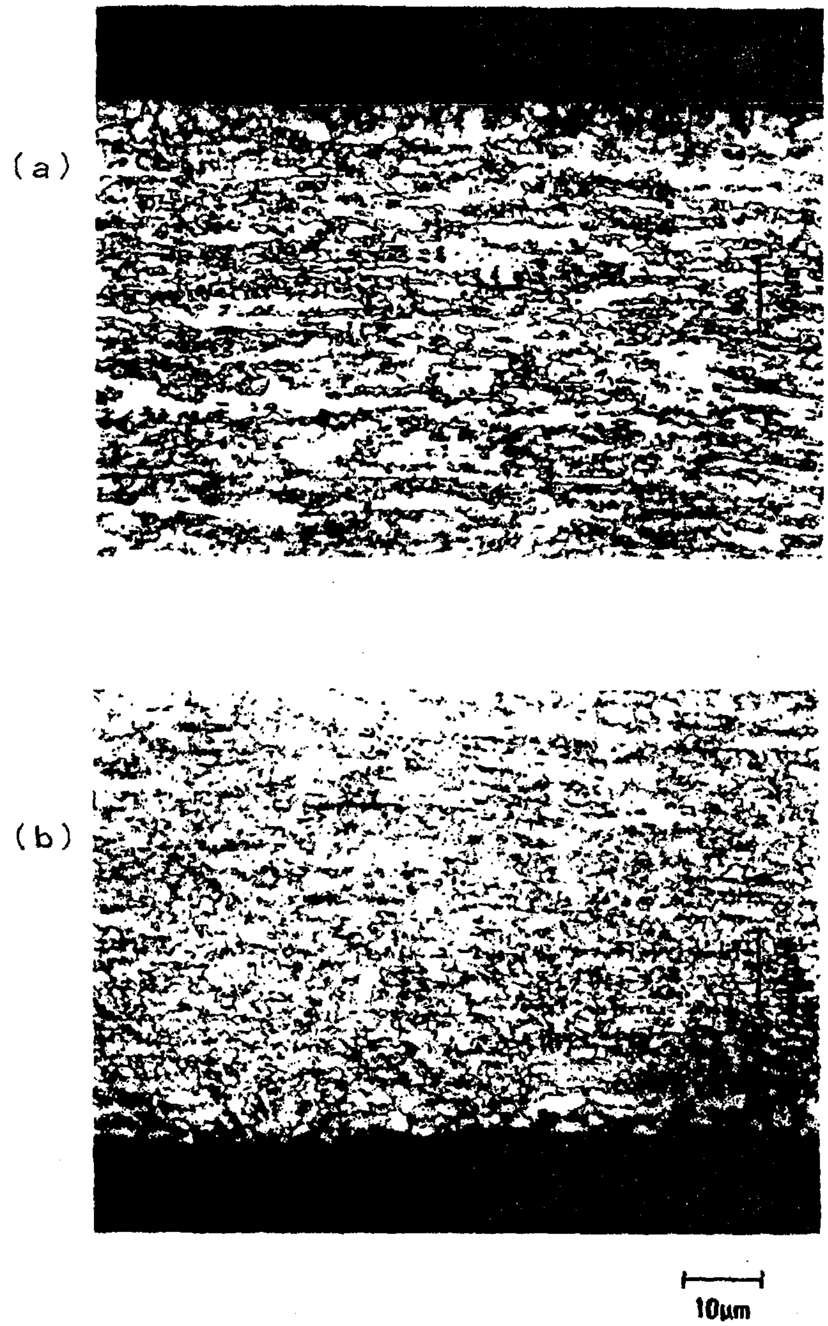

FIG. 4

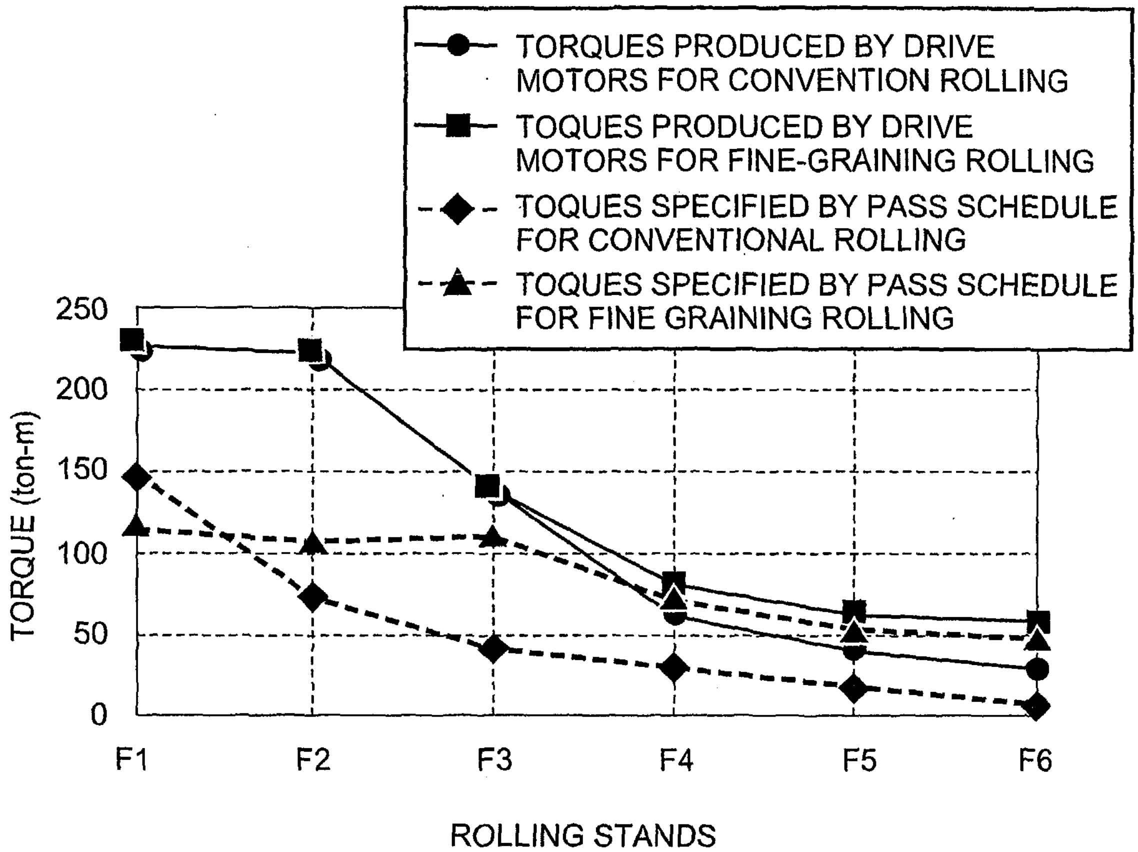
TORQUES PRODUCED BY DRIVE MOTORS FOR CONVENTION ROLLING
TOQUES PRODUCED BY DRIVE MOTORS FOR FINE-GRAINING ROLLING
TOQUES SPECIFIED BY PASS SCHEDULE FOR CONVENTIONAL ROLLING
TOQUES SPECIFIED BY PASS SCHEDULE FOR FINE GRAINING ROLLING
250
200
150
100
50
0
TORQUE (ton-m)
F1
F2
F3
F4
F5
F6
ROLLING STANDS

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP02/10193

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] B21B1/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[7] B21B1/00-1/46, 13/02, 13/14, 37/00-37/78, 45/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Toroku Jitsuyo Shinan Koho	1994-2002
Kokai Jitsuyo Shinan Koho	1971-2002	Jitsuyo Shinan Toroku Koho	1996-2002

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 2002-273501 A (Kabushiki Kaisha Nakayama Seikosho), 25 September, 2002 (25.09.02), Page 5, right column, line 32 to page 7, left column, line 9; Fig. 1 (Family: none)	2-4,9 1,5-8
X A	JP 2000-84601 A (Kawasaki Heavy Industries, Ltd.), 28 March, 2000 (28.03.00), Page 4, left column, line 19 to right column, line 37; Fig. 1 (Family: none)	2-4 1,5-9

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 17 December, 2002 (17.12.02)	Date of mailing of the international search report 14 January, 2003 (14.01.03)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP02/10193

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 6-320202 A (Hitachi, Ltd.), 22 November, 1994 (22.11.94), Page 8, left column, line 43 to page 9, left column, line 11; Figs. 1, 2 (Family: none)	2-4 1,5-9
X A	JP 60-141306 A (Ishikawajima-Harima Heavy Industries Co., Ltd.), 26 July, 1985 (26.07.85), Page 2, lower left column, line 9 to page 3, lower left column, line 20; Fig. 1 (Family: none)	2-4 1,5-9

Form PCT/ISA/210 (continuation of second sheet) (July 1998)