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(71) Applicant: **NIPPON STEEL & SUMITOMO METAL CORPORATION**
Chiyoda-ku,
Tokyo 100-8071 (JP)

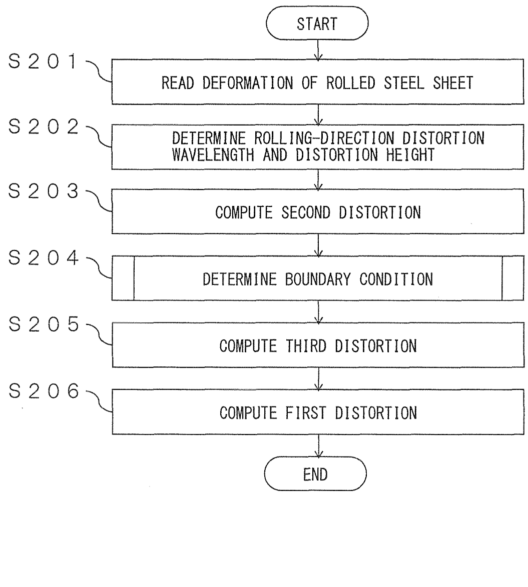
(72) Inventors:
- **AKASHI, Tooru**
  Tokyo 100-8071 (JP)
- **OGAWA, Shigeru**
  Tokyo 100-8071 (JP)

(74) Representative: **Vossius & Partner**
Siebertstrasse 4
81675 München (DE)

(54) DISTORTION CALCULATION METHOD AND ROLLING SYSTEM

(57) A distortion computation method, the method including:
detecting a profile of a steel sheet rolled by a rolling mill;
computing from the detected profile second distortion indicating distortion appearing in an undulation on a surface of the steel sheet;
determining third distortion from correlation between a threshold value of the third distortion indicating distortion corresponding to internal stress of the rolled steel sheet and a wavelength of a rolling-direction component of a profile determined from the detected profile, and the wavelength of the rolling-direction component of the detected profile,
wherein the correlation is computed by buckling analysis from a boundary condition determined from the detected profile, thickness of the steel sheet, width of the steel sheet, tensile strength of the steel sheet, and distribution pattern of the third distortion; and
adding the second distortion to the third distortion so as to compute first distortion indicating difference between distortion corresponding to stress applied to the steel sheet and desired distortion.

Fig.8



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Description

TECHNICAL FIELD

[0001] This invention relates to a method of computing distortion and internal stress of flat-rolled steel and a rolling system.

[0002] The purpose of rolling a steel sheet is to obtain a steel plate or sheet of desired thickness, width and length (hereinafter sometimes called "desired values" or "target value") from a pre-rolled steel by using a rolling mill to apply stress to a steel plate or sheet. However, it is not easy to realize a steel sheet with the desired values, and the surface of the rolled product tends to experience undulations called edge waves and center buckles. The stress exerted on the flat steel by the rolling mill (hereinafter sometimes called "total stress") is consumed 1) by distortion for achieving a predetermined size with the desired values, 2) by distortion that causes the different surface undulations as deviations from the desired values, and 3) as residual stress in the flat steel.

[0003] Realization of rolling that does not produce an undulation on the surface of the steel sheet requires overall ascertainment and control of the relationships among these distortions and stresses. It is especially important to determine and control the difference between the distortion corresponding to the total stress and the distortion for realizing the predetermined size. However, no method for appropriately carrying out this determination has been available up to now.

BACKGROUND ART

[0004] Measurement of the flat steel profile before and after rolling is necessary in order to determine distortion caused by rolling. A number of techniques are known for measuring the profile of a rolled steel sheet. For example, Patent Document 1 teaches a technique for ascertaining flat steel deformation due to strain, which uses a measuring device equipped with multiple optical rangefinders and associates measured steel thickness with position on the plane of the flat steel. Patent Document 1 additionally teaches a technique for inhibiting deformation of a rolled steel sheet by regulating roll position and roll force based on the flat steel deformation measured after rolling.

[0005] Another known technique is to inhibit occurrence of steel sheet profile defects using measurement data obtained by measuring the distortion of a profile prediction model for predicting the distortion of a steel sheet and the distortion of the rolled steel sheet. Patent Document 2 teaches a technique that utilizes measurement data obtained by continuously measuring the distortion of a rolled steel sheet in combination with a predicted profile model for measuring distortion to regulate work roll bending forces so as to sequentially correct profile defects of a steel sheet during rolling. In this case, the predicted profile model is sequentially corrected based on the measured distortion taking into account a dead zone corresponding to a threshold value of the distortion appearing in an undulation on the surface of the rolled steel sheet.

[0006] On the other hand, a technique is known for analyzing the occurrence mechanisms of edge waves, center buckles and other profile defects of steel sheet. Non-patent Document 1 describes a technology for analyzing the mechanisms of edge wave and center buckle occurrence by approximation using edge wave equations and center buckle buckling equations. Non-patent Document 2 describes a technique for analyzing the buckling critical point that is the threshold value of the distortion appearing in an undulation on the surface of the rolled steel sheet.

[0007] Patent Document 3 teaches a technique for applying the buckling equations set out in Non-patent Document 1. Specifically, Patent Document 3 describes a technique for separating the difference between the total stress and the stress corresponding to the desired distortion of the steel sheet by the rolling into the stress component relieved by conversion into distortion appearing in an undulation after cooling and the stress component still remaining inside the steel sheet after the deformation. Patent Document 3 additionally sets out a technique based on the aforesaid for predicting the wave shape occurring when the steel sheet is cooled. In the techniques of Patent Document 3, the stress component relieved by conversion into distortion appearing in an undulation after cooling is obtained by subtracting the stress component still remaining inside the steel sheet after the deformation from the difference between the total stress and the stress corresponding to the desired distortion of the steel sheet by the rolling. Next, the waveform after cooling is predicted by comparing the stress component obtained by the subtraction and the distortion computed from the steepness. Here, the difference between the total stress and the stress corresponding to the desired distortion of the steel sheet by the rolling is treated as a known value estimated from the temperature distribution and the like.

PRIOR ART REFERENCES

Patent Documents

[0008]

Patent Document 1 Unexamined Patent Publication (Kokai) No. H5-237546

Patent Document 2 Unexamined Patent Publication (Kokai) No. H9-295022
Patent Document 3 Patent No. 4262142

Non-patent Documents

[0009]

Non-patent Document 1 Buckling Analysis of Edge Waves and Middle Waves of Cold Rolled Sheet, Journal of the Japan Society for Technology of Plasticity: Plasticity and Forming, Vol.28, No.312 (1987-1) p58-66
Non-patent Document 2 Development of prediction model and prevention method of buckling of TMPC steel plate, CAMP-ISIJ Vol.8 (1995) 1210

SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[0010] Although the control according to Patent Document 1 takes into account the distortion appearing in an undulation on the surface of the rolled steel sheet, it does not take the internal stress of the product into account. Therefore, when the internal stress varies owing to some external disturbance, the internal stress is liable to appear in an undulation on the surface of the steel sheet.
[0011] Further, the technique set out in Patent Document 2 does not offer a method for calculating a dead zone corresponding to a threshold value of the distortion appearing in an undulation on the surface of the rolled steel sheet. In addition, the control by the technique of Patent Document 2 is likely to be complicated because the subject of the control is the rate of crown variation, which is nonlinear.
[0012] Moreover, the teaching of Patent Document 3 is to separate the difference between the total stress and the stress corresponding to the desired distortion of the steel sheet by the rolling into the stress component relieved by conversion into distortion appearing in an undulation and the stress component still remaining inside the steel sheet after the deformation. However, it provides no description or suggestion whatsoever regarding a method by which the difference between the total stress and the stress corresponding to the desired distortion of the steel sheet by the rolling can be calculated based on the stress component relieved by conversion into distortion appearing in an undulation and the stress component still remaining inside the steel sheet after the deformation. In view of the foregoing issues, an object of the present invention is to provide a computation method for computing difference between distortion corresponding to total stress and distortion for achieving predetermined size with desired values based on difference between distortion appearing in an undulation on a steel sheet surface as deviations from the desired values of the rolled steel sheet and distortion corresponding to internal stress of the rolled steel sheet, and also to provide a rolling system.

Means for Solving the Problem

[0013] First, second and third distortions are defined as follows.
[0014] The difference between distortion which should correspond to the stress applied to a steel sheet from a rolling mill and distortion for achieving predetermined size with a desired value is called first distortion. Distortion appearing in an undulation on a surface of a rolled steel sheet that constitutes deviation from a desired value of the rolled steel sheet is called second distortion. Distortion corresponding to internal stress of a rolled steel sheet is called third distortion.
[0015] The gist of the present invention is as set out below.

(1) A distortion computation method, the method including:

detecting a profile of a steel sheet rolled by a rolling mill;
computing from the detected profile second distortion appearing in an undulation on a surface of the steel sheet that constitutes deviation from a desired value of the rolled steel sheet;
determining third distortion from correlation between a threshold value of the third distortion indicating distortion corresponding to internal stress of the rolled steel sheet and a wavelength of a rolling-direction component of the detected profile, and the wavelength of the rolling-direction component of the detected profile,
wherein the correlation is computed by buckling analysis from a boundary condition determined from the detected profile, thickness of the rolled steel sheet, width of the rolled steel sheet, tensile strength of the rolled steel sheet, and distribution pattern of the third distortion; and
adding the second distortion to third distortion so as to compute first distortion indicating difference between distortion corresponding to stress applied to the steel sheet from the rolling mill and stress for achieving prede-

termined size with the desired value.

(2) A distortion computation method as set out in (1), wherein the distribution pattern of the third distortion is computed to be one selected from among patterns whose width-direction component from one end at a central region of the steel sheet to another end at an edge region of the steel sheet is linear, a monotonic rising curve or a monotonic falling curve, a ridge pattern monotonically rising from the central region of the steel sheet and monotonically falling from near the edge region of the steel sheet, and a valley pattern monotonically falling from the central region of the steel sheet and monotonically rising from near the edge region of the steel sheet.
(3) A distortion computation method as set out in (1) or (2), wherein the correlation is computed by buckling equations.
(4) A distortion computation method as set out in (1) or (2), wherein the correlation is determined by a finite element method (FEM) and stored in memory in a table showing correspondence between the wavelength of the rolling-direction component of the detected profile and the threshold value of the third distortion.
(5) A distortion computation method as set out in any of (1) to (4), further including sending a signal indicating the computed first distortion to the rolling mill; wherein the rolling mill is controlled based on the computed first distortion to give the rolled steel sheet the desired profile.
(6) A distortion computation method as set out in (5), further including detecting that an edge wave or a center buckle is formed over at least a half-wavelength.
(7) A distortion computation method as set out in (5), wherein a processing unit is controlled to make the first distortion zero.
(8) A rolling system, the system including:

a rolling mill for rolling a steel sheet;
a profilometer for detecting a profile of the steel sheet rolled by the rolling mill; and
a distortion processing unit for computing from the detected profile second distortion indicating distortion appearing in an undulation on a surface of the steel sheet that constitutes deviation from a desired value of the rolled steel sheet, and, in determining third distortion indicating distortion corresponding to internal stress of the rolled steel sheet from correlation between a threshold value of the third distortion and a profile of the rolled steel sheet, and the detected profile, computing the correlation by buckling analysis from a boundary condition determined by the detected profile, thickness of the rolled steel sheet, width of the rolled steel sheet, tensile strength of the rolled steel sheet, and distribution pattern of the third distortion, adding the computed second distortion and third distortion to compute first distortion indicating difference between distortion corresponding to stress applied to the steel sheet by the rolling mill and stress for achieving predetermined size with the desired value, and sending a signal indicating the computed first distortion to the rolling mill,
the rolling mill being controlled based on the computed first distortion to make the first distortion a desired value.

Effect of the Invention

[0016] Based on second distortion indicating distortion appearing in an undulation on a surface of a rolled steel sheet that constitutes deviation from a desired value of the rolled steel sheet and third distortion corresponding to internal stress of the rolled steel sheet, the present invention can compute first distortion indicating difference between distortion corresponding to stress applied to the steel sheet from a rolling mill and distortion for achieving predetermined size with the desired value.

[0017] Moreover, the present invention can improve steel sheet yield when the tensile strength of the rolled steel sheet is small. In hot rolling, for example, it can improve the yield of the portion (sometimes called the "head") rolled between the start of rolling and the occurrence of coiling tensile strength. Further, in hot rolling, the present invention can improve the yield of the portion (sometimes called the "tail") rolled just before the completion of rolling when tensile strength is low.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018]

FIG. 1 is a circuit block diagram of an example of a rolling system.
FIG. 2 is a function block diagram of a processing unit.
FIG. 3(a) is an analysis image obtained by plotting an example of data analyzed by a profile data analysis unit, and FIG. 3(b) is a diagram illustrating a relationship between a second distortion and position in the width direction of a steel sheet.
FIG. 4 is a diagram illustrating determination processing flow of a boundary condition determination unit.
FIG. 5(a) is a diagram schematically illustrating a boundary condition in a case where distortion appearing in an

undulation on a surface of a steel sheet has the profile of an edge wave, FIG. 5(b) is a diagram schematically illustrating a boundary condition in a case where distortion appearing in an undulation on a surface of a steel sheet has the profile of a center buckle, and FIG. 5(c) is a diagram schematically illustrating a boundary condition in a case where distortion appearing in an undulation on a surface of a steel sheet has the profile of a quarter wave.

FIG. 6(a) is a diagram illustrating displacement of a rolling-direction component of a ridge-valley profile of a steel sheet, FIG. 6(b) is a diagram illustrating a width-direction component of a third distortion distribution used when computing correlation between an average value of a plasticity distribution and a half-wavelength of the undulation of the steel sheet, FIG. 6(c) is a diagram illustrating correlation between the average value of the plasticity distribution and the half-wavelength of the undulation of the steel sheet, and FIG. 6(d) is a diagram illustrating a computed third distortion distribution.

FIG. 7(a) is a diagram illustrating a distribution of second distortion from a width-direction central region to a width direction edge region of a steel sheet, FIG. 7(b) is a diagram illustrating a distribution of third distortion from the width-direction central region to the width-direction edge region of the steel sheet, and FIG. 7(c) is a diagram illustrating a distribution of first distortion, obtained by adding the second distortion to third distortion, from the width-direction central region to the width-direction edge region of the steel sheet.

FIG. 8 is a diagram illustrating an example of a computation flow for computing first distortion.

FIG. 9 is a circuit block diagram of another example of a rolling system.

FIG. 10 is a diagram illustrating another example of a computation flow for computing first distortion.

FIG. 11 is a circuit block diagram of another example of a rolling system.

FIG. 12 is a diagram illustrating other examples of third distortion distribution.

MODES FOR CARRYING OUT THE INVENTION

[0019] A rolling system according to the present invention, which is equipped with a power supply selector circuit, is explained below with reference to FIGs. 1 to 12. To begin with, a first embodiment of the rolling system is explained with reference to FIGs. 1 to 8.

[0020] FIG. 1 is a circuit block diagram of an example of a rolling system according to a first embodiment.

[0021] The rolling system, designated by reference symbol 1, has a distortion processing unit 10, a hot tandem rolling mill 20 (hereinafter sometimes called simply "rolling mill 20") for rolling a steel sheet 101 in the direction of arrow A. The rolling system 1 additionally includes a profilometer 30, thickness meter 31, width meter 32 and tensile strength meter 33 for detecting the profile, thickness, width and tensile strength of the rolled steel sheet 101.

[0022] The distortion processing unit 10 has an arithmetic unit 11, a memory unit 12, and an I/O unit 13. The hot tandem rolling mill 20 has multiple stands 21 for sequentially rolling the steel sheet 101, multiple conveyor rollers 22 for conveying the steel sheet 101, and a rolling control unit 23 for regulating the roll positions and roll pressures of the individual stands 21.

[0023] The arithmetic unit 11 is equipped with a CPU (Central Processing Unit) and a DSP (digital signal processor). Utilizing programs stored in the memory unit 12, the arithmetic unit 11 processes data received from the profilometer 30, thickness meter 31, width meter 32 and tensile strength meter 33 to compute first distortion ε_1 indicating the difference between distortion corresponding to total stress and distortion for achieving predetermined size with desired values.

[0024] The memory unit 12 has a nonvolatile memory for storing various programs and a volatile memory for temporarily storing data. The memory unit 12 stores programs executed by the arithmetic unit 11 and an OS and other basic software required for executing the programs. The memory unit 12 also stores detection data received from the profilometer 30, thickness meter 31, width meter 32, and tensile strength meter 33.

[0025] The I/O unit 13 converts detection data transmitted from the profilometer 30, thickness meter 31, width meter 32 and tensile strength meter 33 into data processable by the arithmetic unit 11. The detection data received by the I/O unit 13 is stored in the memory unit 12. The I/O unit 13 sends the data processed by the arithmetic unit 11 to the rolling control unit 23.

[0026] Each of the stands 21 has a pair of upper and lower work rolls and a pair of backup rolls arranged to sandwich the work rolls. The stands 21 can have any number of rolls and, for example, can be two-high, four-high or six-high. Moreover, each stand 21 comprises profile control actuators (not illustrated). The profile control actuators operate in accordance with control signals received from the rolling control unit 23 to apply predetermined rolling loads to the steel sheet 101 and impart various contours to the steel sheet 101 by bender, work roll shift, pair cross and other rolling.

[0027] The profilometer 30 comprises multiple point-like light sources and an image pickup device. It detects the profile of the rolled steel sheet 101 by imaging light sequentially projected from the multiple point-like light sources onto upper surface of the steel sheet 101 in the rolling direction and vertically.

[0028] The thickness meter 31 is an X-ray thickness meter that detects the thickness of the steel sheet 101.

[0029] The width meter 32 is a spot-type laser beam distance meter that detects the width of the steel sheet 101.

[0030] The tensile strength meter 33 includes two detectors arranged at a predetermined spacing. It detects the tensile strength of the steel sheet 101 by using the two detectors to detect detection holes formed in the steel sheet 101.

[0031] FIG. 2 is a function block diagram of the arithmetic unit 11 of the distortion processing unit 10.

[0032] The arithmetic unit 11 has a profile data analyzing unit 51, a second-distortion arithmetic unit 52, a boundary condition determination unit 53, a third-distortion arithmetic unit 54, and a first-distortion arithmetic unit 55. The arithmetic unit 11 executes the programs stored in the memory unit 12 to perform the processing by these constituent elements 51 to 255.

[0033] The profile data analyzing unit 51 analyzes the profile of the steel sheet 101 detected by the profilometer 30 to determine the wavelength 2L of the rolling-direction component of an undulation appearing periodically on the steel sheet 101 and the height direction displacement at every detection site on the surface of the steel sheet 101.

[0034] FIG. 3(a) illustrates an analysis image 300 obtained by plotting an example of data analyzed by the profile data analyzing unit 51 from the profile of the steel sheet 101 detected by the profilometer 30.

[0035] The analysis image 300 has an x coordinate axis, a y coordinate axis and a z coordinate axis. The x coordinate axis corresponds to the rolling direction at the width-direction central region of the steel sheet 101. The y coordinate axis corresponds to the width direction of the steel sheet 101. The z coordinate axis corresponds to the height direction of the steel sheet 101.

[0036] The sine-wave shaped cross-section of the analysis image 300 corresponds to a section of a width-direction edge region of the steel sheet 101. As the distortion profile appearing in an undulation of the steel sheet 101 appears as edge waves, the analysis image 300 has a sine-wave-shaped cross-section at the width-direction edge region. In the case where the distortion profile appearing in an undulation of the steel sheet 101 appears as center buckle, a sine-wave-shaped cross-section is formed along the x coordinate axis corresponding to the width-direction central region of the steel sheet 101, with no formation of an undulation at the width-direction edge region of the steel sheet 101.

[0037] The second-distortion arithmetic unit 52 computes from data analyzed by the profile data analyzing unit 51 second distortion ε_2 appearing in an undulation on a surface of the steel sheet that constitutes deviation from a desired value of the rolled steel sheet. First, the second-distortion arithmetic unit 52 sequentially computes distortion ε_j, at j^{th} width positions in accordance with Mathematical (1) to (3).

$$\varepsilon_j = \frac{\sum_{i=1}^{L}(ds_{ij} - dx_{ij})}{\sum_{i=1}^{L} dx_{ij}} \qquad (1)$$

$$ds_{ij} = \sqrt{(dx_{ij})^2 + (dz_{ij})^2} \qquad (2)$$

$$\varepsilon'_j = \varepsilon_j - \varepsilon_{(j=1)} \qquad (3)$$

[0038] Here, dx_{ij} is the distance between adjacent detection sites in the x-axis direction and dz_{ij} is the distance in the z-axis direction between detection sites corresponding to dx_{ij}. L is the half-wavelength of the rolling-direction component of an undulation appearing periodically on the steel sheet 101 and ε_j is a value including the z-direction height of the width-direction central region of the steel sheet 101 and the value of the second distortion ε_2 of the j^{th} site in the width direction. Further, $\varepsilon_{(j=1)}$ of Mathematical (3) is the z-direction height of the width-direction central region. Distortion ε'_j computed by Mathematical (3) corresponds to the value of second distortion ε_2 at the j^{tn} site in the width direction.

[0039] FIG. 3(b) is a diagram illustrating a relationship between second distortion ε_2 computed using Mathematical (1) to (3) and width-direction position of a steel sheet 101.

[0040] The boundary condition determination unit 53 determines from data analyzed by the profile data analyzing unit 51 whether the distortion appearing in an undulation on the surface of the rolled steel sheet 101 is edge wave, center buckle, or quarter wave.

[0041] FIG. 4 is a diagram illustrating the determination processing flow of the boundary condition determination unit 53.

[0042] First, in step S101, the boundary condition determination unit 53 compares the height of a width-direction quarter region of the steel sheet 101 with the heights of the width-direction central region and edge region of the steel sheet 101. When the boundary condition determination unit 53 determines that the peak height of the width-direction quarter region of the steel sheet 101 is higher, processing moves to step S102. On the other hand, when the boundary condition determination unit 53 determines that the peak height of the width-direction quarter region of the steel sheet 101 is lower, processing goes to step S103.

[0043] When the boundary condition determination unit 53 determines in step S101 that the height of the width-direction quarter region of the steel sheet 101 is higher, the boundary condition determination unit 53 determines in step S102 that the profile of the distortion appearing in an undulation on the surface of the steel sheet 101 is quarter wave.

[0044] When the boundary condition determination unit 53 determines in step S101 that the height of the width-direction quarter region of the steel sheet 101 is lower, the boundary condition determination unit 53 compares the heights of the width-direction central region and edge region of the steel sheet 101.

[0045] When the boundary condition determination unit 53 determines in step S103 that the height of the width-direction central region of the steel sheet 101 is higher, the boundary condition determination unit 53 determines in step S104 that the profile of the distortion appearing in an undulation on the surface of the steel sheet 101 is center buckle.

[0046] When the boundary condition determination unit 53 determines in step S103 that the height of the width-direction central region of the steel sheet 101 is lower, the boundary condition determination unit 53 determines in step S105 that the profile of the distortion appearing in an undulation on the surface of the steel sheet 101 is edge wave.

[0047] FIG. 5 is a set of diagrams schematically illustrating boundary conditions determined by the undulation of the steel sheet 101. FIG. 5(a) illustrates a boundary condition in the case where the profile of distortion appearing in an undulation on the surface of the steel sheet is edge wave. FIG. 5(b) illustrates a boundary condition in the case where the profile of distortion appearing in an undulation on the surface of the steel sheet is center buckle. FIG. 5(c) illustrates a boundary condition in the case where the profile of distortion appearing in an undulation on the surface of the steel sheet is quarter wave.

[0048] The distortion profile appearing in an undulation on the surface of the steel sheet 101 illustrated in FIG. 5(a) is edge wave. The boundary condition of the steel sheet 101 in FIG. 5(a) is a condition wherein width-direction displacement and height-direction displacement are restrained at the central region and unrestrained at the edge region of the width-direction section (hereinafter sometimes called the "C-section").

[0049] The distortion profile appearing in an undulation on the surface of the steel sheet 101 illustrated in FIG. 5(b) is center buckle. The boundary condition of the steel sheet 101 in FIG. 5(b) is a condition wherein rotation around the rolling direction is constrained at the central region and height-direction displacement is constrained at the edge region of the C-section.

[0050] The distortion profile appearing in an undulation on the surface of the steel sheet 101 illustrated in FIG. 5(c) is quarter wave. The boundary condition of the steel sheet 101 in FIG. 5(c) is a condition wherein width-direction displacement and height-direction displacement are restrained at both the central region and edge region of the C-section.

[0051] The third-distortion arithmetic unit 54 computes third distortion ε_3 indicating distortion corresponding internal stress of the rolled steel sheet 101. The third-distortion arithmetic unit 54 performs buckling analysis using buckling equations to compute the third distortion ε_3 from the thickness, width and tensile strength of the rolled steel sheet 101, the boundary condition determined by the boundary condition determination unit 53, and the wavelength of the rolling-direction component of the undulation appearing periodically on the steel sheet 101.

[0052] The third-distortion arithmetic unit 54 solves the buckling equations indicated in Mathematical (4) to (11) for each predetermined width-direction position. The third-distortion arithmetic unit 54 determines threshold values (criteria) of the third distortion ε_3 of the rolled steel sheet 101 from the solutions obtained. The threshold value of the third distortion ε_3 determined by the third-distortion arithmetic unit 54 is a value indicating that the steel sheet 101 experiences second distortion when distortion equal to or greater than this value remains in the steel sheet 101. It is assumed here that second distortion occurs in the rolled steel sheet 101 in the case where distortion equal to or greater than the third distortion ε_3 threshold value value remains in the rolled steel sheet 101. In other words, it is assumed that a steel sheet 101 in which second distortion occurred has residual internal distortion corresponding to at least the threshold value of the third distortion ε_3.

[0053] In Mathematical (4), the third-distortion arithmetic unit 54 solves the buckling equation of distortion ε_x^* by finding the solution satisfying F = 0 as described in Non-patent Document 1.

$$
\begin{aligned}
F &= \delta(\delta^2 \pi) \\
&= 2\int\int_R [\delta w_{1,x} \{h\sigma_f + Eh(\varepsilon_m^* - \varepsilon_x^*)\} w_{1,x}]\, dx\, dy \\
&+ 2D\int\int_R [\delta w_{1,xx} w_{1,xx} + \delta w_{1,yy} w_{1,yy} \\
&+ \nu(\delta w_{1,xx} w_{1,yy} + \delta w_{1,yy} w_{1,xx}) \\
&+ 2(1-\nu)\delta w_{1,xy} w_{1,xy}]\, dx\, dy \qquad (4)
\end{aligned}
$$

[0054] Here, w indicates the height-direction displacement of the undulation, subscript 1 indicates displacement increment after buckling, and ε_m^* is expressed by

$$\varepsilon_m^* = \int_{-b}^{b} \varepsilon_x^* \, dy \,/(2b) \qquad (5)$$

and indicates the average value of plastic strain distribution ε_x^*. Further, b is half the length of the width of the rolled steel sheet 101, h is the thickness of the rolled steel sheet 101, and σ_f is the tensile strength of the rolled steel sheet 101. E indicates Young's modulus and ν indicates Poisson's ratio. And D is

$$D = Eh^3/12(1-\nu^2) \qquad (6)$$

In addition, the width-direction component w (y) of the height-direction displacement of the undulation of the rolled steel sheet 101 is, as indicated by Mathematical 7, defined as a cubic function with origin at the width-direction central region.

$$w(y) = a_1 + a_2 y^1 + a_3 y^2 + a_4 y^3 \qquad (7)$$

[0055] On the other hand, the rolling-direction component of the height-direction displacement of the undulation of the rolled steel sheet 101 is defined as a sine curve of wavelength 2L. When the buckling equations are solved, wavelength 2L is given as a variable within a predetermined range.

[0056] The rolling-direction component of the undulation of the steel sheet 101 is illustrated in FIG. 6(a). From this, the displacement of the undulation of the steel sheet 101 becomes as indicated by Mathematical (8).

$$w(x, y) = w(y)\sin(\pi x / L) \qquad (8)$$

[0057] Moreover, as illustrated by FIG. 6(b) and Mathematical (9), the width-direction component of the third distortion distribution is defined as a non-dimensional quadratic curve with origin at the width-direction central region.

$$\varepsilon_x^*(y) = (1/b^2)\, y^2 \quad (0 \leqq y \leqq b) \qquad (9)$$

[0058] In addition, Mathematical (10) is derived when Mathematical (3) is simplified by integration over half-wavelength L.

$$\begin{aligned} F = \; & L\int_0^b \delta w_1 \{h\overline{\sigma}_1 + Eh(\varepsilon_m^* - \varepsilon_x^*)\} w_1 dy (\pi/L)^2 \\ & + DL\int_0^b [\delta w_1 w_1 (\pi/L)^4 + \delta w_{1,yy} w_{1,yy} \\ & + \nu(\delta w_1 w_{1,yy} + \delta w_{1,yy} w_1)(-(\pi/L)^2) \\ & + 2(1-\nu)\delta w_{1,y} w_{1,y} (\pi/L)^2] dy \qquad (10) \end{aligned}$$

[0059] In addition, in order to solve Mathematical (10) by discretization, Mathematical (10) is discretized as indicated by Mathematical (11).

$$\int_0^b F dy = \Sigma \int_\Gamma F^e dy \qquad (11)$$

[0060] The right side here is the result of integrating the elements. The correlation between the average value ε_m* of the plastic strain distribution ε_x* and the half-wavelength L of the rolling-direction component of the undulation of the steel sheet 101 can be derived by developing Mathematical (11) into determinants to obtain generalized characteristic values of the discretized elements as a whole. When Mathematical (11) is solved, the boundary condition decided based on the determination of the boundary condition determination unit 53 is applied.

[0061] FIG. 6(c) is a diagram illustrating correlation between the average value ε_m* of the plastic strain distribution ε_x* computed by Mathematical (11) and the half-wavelength L of the rolling-direction component of the undulation of the steel sheet 101. As illustrated in FIG. 6(c), when the half-wavelength L of the rolling-direction component of the undulation of the steel sheet 101 is increased, the average value ε_m* of the plastic strain distribution ε_x* first falls sharply, then declines slowly to assume a very small level value, and thereafter increases gradually.

[0062] From the correlation between the average value ε_m* of the plastic strain distribution ε_x* and the half-wavelength L of the rolling-direction component of the undulation of the steel sheet 101, the third-distortion arithmetic unit 54 determines distortion ε_{mS} corresponding to the half-wavelength L of the rolling-direction component of the undulation of the steel sheet 101. The value of the half-wavelength L of the rolling-direction component of the undulation of the steel sheet 101 used here is the value the profile data analyzing unit 51 analyzes from the profile of the steel sheet 101 detected by the profilometer 30.

[0063] Next, the third-distortion arithmetic unit 54 determines a threshold value of the third distortion of the rolled steel sheet 101 by associating the computed distortion ε_{mS} and the width-direction component of the third distortion distribution indicated by the non-dimensional quadratic curve. The threshold value of the third distortion ε_3 is determined by defining the distortion ε_{mS} computed by the third-distortion arithmetic unit 54 as the edge region value of the width-direction component of the third distortion indicated by the non-dimensional quadratic curve.

[0064] FIG. 6(d) is a diagram illustrating a relationship between the threshold value of the third distortion ε_3 determined by the third-distortion arithmetic unit 54 and the width-direction position of the steel sheet 101. The distortion ε_{mS} is the third distortion at the width-direction edge region.

[0065] The first-distortion arithmetic unit 55 computes the first distortion ε_1 by adding the second distortion ε_2 computed by the second-distortion arithmetic unit 52 to the third distortion ε_3 computed by the third-distortion arithmetic unit 54.

[0066] FIG. 7(a) is a diagram illustrating a distribution of the second distortion ε_2 from the width-direction central region to the width-direction edge region of the steel sheet 101. FIG. 7(b) is a diagram illustrating a distribution of the third distortion ε_3 from the width-direction central region to the width-direction edge region of the steel sheet 101. FIG. 7(c) is a diagram illustrating a distribution of the first distortion ε_1 obtained by adding the second distortion ε_2 to third distortion s_3, from the width-direction central region to the width-direction edge region of the steel sheet 101.

[0067] Now follows an explanation of the flow of the computation of the first distortion ε_1 by the distortion processing unit 10.

[0068] FIG. 8 is a diagram illustrating the computation flow of the distortion processing unit 10 for computing the first distortion ε_1.

[0069] First, in step S201, the distortion processing unit 10 reads detection data stored in the memory unit 12. The data read by the distortion processing unit 10 are data detected by the profilometer 30, thickness meter 31, width meter 32, and tensile strength meter 33.

[0070] Next, in step 202, the profile data analyzing unit 51 analyzes the read detection data to determine the wavelength 2L of the rolling-direction component of the undulation appearing periodically on the steel sheet 101 and the height direction displacement at every detection site on the surface of the steel sheet 101.

[0071] Next, in step 203, the second-distortion arithmetic unit 52 computes from the data analyzed by the profile data analyzing unit 51 the second distortion ε_2 appearing in an undulation on the surface of the steel sheet that constitutes deviation from a desired value of the rolled steel sheet.

[0072] Next, in step 204, the boundary condition determination unit 53 determines from the data analyzed by the profile data analyzing unit 51 whether the distortion appearing in an undulation on the surface of the rolled steel sheet 101 is edge wave, center buckle, or quarter wave.

[0073] Next, in step 205, the third-distortion arithmetic unit 54 computes the third distortion ε_3 indicating distortion corresponding internal stress of the rolled steel sheet 101. The third-distortion arithmetic unit 54 performs buckling analysis to compute the third distortion ε_3 from the thickness, width and tensile strength of the rolled steel sheet 101, the boundary condition determined by the boundary condition determination unit 53, and the wavelength of the rolling-direction component of the undulation appearing periodically on the steel sheet 101.

[0074] Then, in step 206, the first-distortion arithmetic unit 55 computes the first distortion ε_1 by adding the second distortion ε_2 computed in step 203 to the third distortion ε_3 computed in step 205.

[0075] The computation flow of the arithmetic unit 11 is explained in the foregoing. The arithmetic unit 11 includes the profile data analyzing unit 51, second-distortion arithmetic unit 52, boundary condition determination unit 53, third-distortion arithmetic unit 54, and first-distortion arithmetic unit 55; it computes the first distortion ε_1 from the second distortion ε_2 appearing in an undulation on the surface of the rolled steel sheet and the third distortion ε_3 computed by buckling equations.

[0076] Although the third distortion ε_3 has n modes that differ in period, the arithmetic unit 11 takes only the 1st mode into consideration. This is because theoretically there is no need to consider the second and higher modes within the thickness and width ranges of the steel sheets to be rolled by the rolling system 1.

[0077] The hot tandem rolling mill 20 has the multiple stands 21 for sequentially rolling the steel sheet 101, multiple conveyor rollers 22 for conveying the steel sheet 101, and rolling control unit 23 for regulating the roll positions and roll pressures of the individual stands 21.

[0078] Based on the first distortion ε_1 computed by the arithmetic unit 11, the rolling control unit 23, which is a sequencer, performs PID control to individually regulate the roll positions, roll forces and other rolling conditions of the multiple stands 21 so as to achieve the desired profile of the rolled steel sheet. For example, the rolling control unit 23 can control the roll positions, roll forces and other rolling conditions of the multiple stands 21 so as to make the first distortion of the rolled steel sheet zero. Moreover, the rolling control unit 23 can control the roll positions, roll forces and other rolling conditions of the multiple stands 21 so that edge waves having a steepness λ of 1% are formed. If the first distortion computed based on the second distortion and third distortion is fed back to the rolling mill, it becomes possible to feedback-control the first distortion to a desired value. In addition, if the roll positions, roll forces and other rolling conditions of the multiple stands 21 are controlled to make the first distortion of the rolled steel sheet zero, strain relieved when the rolled steel sheet is cut becomes zero, so that the cut steel sheet maintains its flatness.

[0079] The profilometer 30, thickness meter 31, width meter 32, and tensile strength meter 33 respectively detect the profile and the like of the steel sheet 101 rolled by multiple stands 21 under respective regulated rolling conditions and send the detection data to the arithmetic unit 10.

[0080] The arithmetic unit 10 feedback-controls distortion of the steel sheet 101 by feeding back to the hot tandem rolling mill 20 the first distortion ε_1 computed based on detection data detected by the profilometer 30, thickness meter 31, width meter 32, and tensile strength meter 33.

[0081] The first embodiment of the rolling system is explained in the foregoing.

[0082] Next, a second embodiment of the rolling system is explained with reference to FIGs. 9 and 10.

[0083] FIG. 9 is a circuit block diagram of a rolling system 2 in accordance with the second embodiment.

[0084] The rolling system 2 differs from the rolling system 1 illustrated in FIG. 1 in that the distortion processing unit 10 is connected to a host computing system 40 rather than to the thickness meter 31, width meter 32, and tensile strength meter 33.

[0085] The host computing system 40 comprises steel sheet profile tables 41 and third distortion computation tables 42.

[0086] Each steel sheet profile table 41 contains the identification number of a steel sheet rolled by the rolling mill 20, estimated thickness and width of the rolled steel sheet, and correspondence with estimated tensile strength of the rolled steel sheets.

[0087] Each third distortion computation table 42 contains a correlation between the average value ε_m^* of plastic strain distribution ε_x^* and the half-wavelength L of the rolling-direction component of the undulation of a steel sheet. The arithmetic unit 11 generates the third distortion computation table 42 by applying the FEM (Finite Element Method) under given computation conditions to solve the buckling equations set out in Mathematical (4) to (11). Multiple tables are included for each computation condition. The FEM computation conditions include, inter alia, the width, thickness, unit tensile strength, and distribution profile of the third distortion ε_3 of the rolled steel sheet.

[0088] FIG. 10 is a diagram illustrating the computation flow for computing the first distortion ε_1 in the rolling system 2.

[0089] The processing performed in steps S301 to S304 and S306 of the computation flow illustrated in FIG. 10 is the same as that performed in steps S201 to S204 and S206 of the computation flow illustrated in FIG. 8. In other words, the processing flow illustrated in FIG. 10 differs from the processing flow illustrated in FIG. 8 in the processing of step S305. Specifically, in the computation flow illustrated in FIG. 10, the arithmetic unit 11 does not compute the third distortion ε_3 by solving the buckling equations set out in Mathematical (4) to (11) but instead determines the third distortion ε_3 by referring to the steel sheet profile tables 41 and the third distortion computation tables 42.

[0090] The second embodiment of the rolling system is explained in the foregoing.

[0091] Next, a third embodiment of the rolling system is explained with reference to FIG. 11.

[0092] FIG. 11 is a circuit block diagram of a rolling system 3 in accordance with the second embodiment.

[0093] The rolling system 3 differs from the rolling system 1 illustrated in FIG. 1 in being equipped with a reversible rolling mill 25 instead of the hot tandem rolling mill 20. In the reversible rolling mill 25, a steel sheet 103 is, as indicated by a left-right arrow C, reciprocally conveyed in the left and right directions of the reversible rolling mill 25 by the conveyor rollers 22. The rolling system 3 is therefore equipped on one side with the profilometer 30, thickness meter 31, width meter 32 and tensile strength meter 33 and additionally on the other side with a profilometer 35, thickness meter 36, width meter 37 and tensile strength meter 38. The arithmetic unit 10 computes the first distortion ε_1 based on the detection data of the profilometer 30, thickness meter 31, width meter 32 and tensile strength meter 33, and also computes the first distortion ε_1 based on the detection data of the profilometer 35, thickness meter 36, width meter 37 and tensile strength meter 38.

[0094] The third embodiment of the rolling system is explained in the foregoing.

[0095] Modifications of the rolling system are explained in the following.

[0096] Although the rolling systems 1 to 3 were explained regarding hot rolling, the rolling systems can also be applied in cold rolling.

[0097] While the distortion processing unit 10 of the rolling systems 1 to 3 is not incorporated in the rolling mill 20 or reversible rolling mill 25, the functional and structural features of the distortion processing unit 10 can be incorporated into the rolling control unit 23 of the rolling mill 20. In the rolling system 2, moreover, the functional and structural features of the distortion processing unit 10 can be incorporated into the rolling control unit 23, profilometer 30 or host computing system 40.

[0098] In the rolling system 1, although the profilometer 30, thickness meter 31, width meter 32 and tensile strength meter 33 are installed only on the downstream side of the final stand 21, it is possible to install them on the downstream side of every multiple stand 21. Moreover, while the control signals from the rolling control unit 23 are sent to all of the multiple stands 21, it is possible to send them to only the final stand 21.

[0099] In the rolling system 2, although the profilometer 30 is installed only on the downstream side of the final stand 21, it can be installed on the downstream side of every multiple stand 21. Moreover, while the control signals from the rolling control unit 23 are sent to all of the multiple stands 21, it is possible to send them to only the final stand 21.

[0100] In the rolling system 3, although the profilometer 35, thickness meter 36, width meter 37 and tensile strength meter 38 are installed in addition to the profilometer 30, thickness meter 31, width meter 32 and tensile strength meter 33, it is possible to install only the profilometer 30, thickness meter 31, width meter 32 and tensile strength meter 33 on one or the other side of the stand 21.

[0101] Although the second-distortion arithmetic unit 52 computes the second distortion ε_2 by Mathematical (1) to (3), it can instead compute the second distortion ε_2 using the following Mathematical (12) indicating steepness λ.

$$\lambda = h \cdot w(y)^* / (2L^*) = (2/\pi) \cdot (\Delta\varepsilon)^{0.5} \qquad (12)$$

[0102] Moreover, in the case where the detection data output by the profilometer 30 are solely data associated with the width-direction central region and opposite edge regions, the second-distortion arithmetic unit 52 can fit the width-direction component of the undulation to a quadratic curve based on these data.

[0103] In the case where the detection data output by the profilometer 30 are solely data associated with the width-direction central region and opposite edge regions, and the quarter regions (points midway of the central region and edge regions) of the work side (WS) and drive side (DS), the second-distortion arithmetic unit 52 can fit the width-direction component of the undulation to quadratic to quartic curves based on these data.

[0104] When the third-distortion arithmetic unit 54 solves the buckling equations, the width-direction distribution of the third distortion is defined to be a non-dimensional quadratic curve with origin at the width-direction central region. However, it can instead be defined as linear, cubic or quartic. Moreover, when the third-distortion arithmetic unit 54 solves the buckling equations, the width-direction distribution of the third distortion can be defined as a ridge pattern monotonically rising from the central region of the steel sheet and monotonically falling from near the edge region of the steel sheet. Furthermore, the width-direction distribution of the third distortion can be defined as a valley pattern monotonically falling from the central region of the steel sheet and monotonically rising from near the edge region of the steel sheet. Mathematical (13) to (22) and FIGs. 12(a) 12(e) show examples of directional distributions of the third distortion.

$$\varepsilon_x^* (y) = (1/b)\, y \quad (0 \leqq y \leqq b) \tag{13}$$

$$\varepsilon_x^* (y) = -(1/b)\, y + 1 \quad (0 \leqq y \leqq b) \tag{14}$$

$$\varepsilon_x^* (y) = (1/b^2)\, y^2 \quad (0 \leqq y \leqq b) \tag{15}$$

$$\varepsilon_x^* (y) = -(1/b^2)\, y^2 + 1 \quad (0 \leqq y \leqq b) \tag{16}$$

$$\varepsilon_x^* (y) = (1/b^3)\, y^3 \quad (0 \leqq y \leqq b) \tag{17}$$

$$\varepsilon_x^* (y) = -(1/b^3)\, y^3 + 1 \quad (0 \leqq y \leqq b) \tag{18}$$

$$\varepsilon_x^* (y) = (1/b^4)\, y^4 \quad (0 \leqq y \leqq b) \tag{19}$$

$$\varepsilon_x^* (y) = -(1/b^4)\, y^4 + 1 \quad (0 \leqq y \leqq b) \tag{20}$$

$$\begin{aligned} \varepsilon_x^* (y) &= (1/b^2)\, y^2 \quad (0 \leqq y \leqq b - 1/k) \\ &= -ky + A \quad (b - 1/k \leqq y \leqq b) \end{aligned} \tag{21}$$

where

$$A = -(1 - kb) + (1 - kb)^2 / (kb)^2$$

$$\varepsilon_x^*(y) = -(1/b^2)\,y^2 + 1 \quad (0 \leqq y \leqq b - 1/k) \qquad (22)$$
$$= ky + B \quad (b - 1/k \leqq y \leqq b)$$

where

$$B = 1 + (1 - kb) - (1 - kb)^2/(kb)^2$$

[0105] Further, the profilometer 30 can have the ability to detect that an edge wave or center buckle has been formed over a length corresponding to the half-wavelength L. For example, if the profilometer 30 has the ability to detect the heights of the opposite width-direction edge regions and the central region, then when the heights become the same as the height of the end of the rolled head, it can detect that an edge wave or center buckle appearing on the surface of the rolled steel sheet has been formed over a half-wavelength L. When the profilometer 30 detects that an edge wave or center buckle has been formed from the end of the rolled head over at least the length of a half-wavelength L, it sends a half-wavelength detection signal to the distortion processing unit 10. Upon receiving the half-wavelength detection signal, the distortion processing unit 10 starts the processing of the first distortion ε_1 computation flow illustrated in FIG. 8. So if the profilometer 30 has the ability to detect that an edge wave or center buckle has been formed over a prescribed length such as a half-wavelength L, the processing of the first distortion ε_1 computation flow can be initiated when an edge wave or center buckle of the prescribed length from the rolled head is detected. The processing of the first distortion ε_1 computation flow can therefore be promptly commenced at a rolled head with relatively low tensile strength, thereby making it possible to enhance the flatness of the rolled steel sheet. Moreover, the flatness of the rolled steel sheet can also be improved at the rolled tail where tensile strength is low.

[0106] Furthermore, in the rolling system 2, while the steel sheet profile table 41 and third distortion computation table 42 are deployed in the host computing system 40, they can instead be stored in the memory unit 12 of the distortion processing unit 10. Moreover, in the case where the functional and structural features of the distortion processing unit 10 are incorporated into the rolling control unit 23 or the profilometer 30, the steel sheet profile table 41 and third distortion computation table 42 can be included in the rolling control unit 23 or the profilometer 30.

[0107] Also in the rolling system 3, similarly to in the rolling system 2, the distortion processing unit 10 can be configured to connect with the host computing system 40 instead of the thickness meter 31, width meter 32, and tensile strength meter 33.

WORKING EXAMPLES

[0108] Two working examples were carried out. In one example, a steel sheet was rolled in the hot tandem rolling system 1 illustrated in FIG. 1, and in the other example a steel plate was rolled in the hot reversible rolling system 3 illustrated in FIG. 11.

[0109] With the hot tandem rolling system 1, a 35-mm thick, 1200-mm wide steel plate was rolled into a 3-mm thick, 1200-mm wide steel sheet. The tensile strength at this time was 20 MPa. The measurement data measured by the profilometer 30 were fitted to a quartic curve. Then, based on the computed first distortion ε_1, the work role bending forces of the final stand 21 were corrected in real time by the control signal produced by the rolling control unit 23 so as to make the first distortion of the rolled steel sheet zero.

[0110] As a result, in terms of steel sheet profile accuracy, the profile accuracy of the hot-rolled steel sheet was 20% better than when using the conventional profilometer method.

[0111] With the hot reversible rolling system 3, a 200-mm thick, 2000-mm wide steel slab was rolled into a 15-mm thick, 4000-mm wide steel plate. The tensile strength at this time was 0 MPa. The measurement data measured by the profilometer 30 were fitted to a quartic curve. Then, based on the computed first distortion ε_1, the work role bending forces were corrected in the second and later passes by the control signal produced by the rolling control unit 23 so as to make the first distortion of the rolled steel sheet zero.

[0112] As a result, in terms of steel plate profile accuracy, the profile accuracy of the steel plate by reverse rolling was 15% better than when using the conventional profilometer method.

[0113] Although examples of the invention are explained in the foregoing, all of the examples and conditions set forth here are presented for the purpose of facilitating an understanding of the invention and the concept of the invention applied to technology, and, particularly, the examples and conditions set forth are not intended to limit the scope of the invention nor do the configurations of such examples of the specification indicate merits and demerits of the invention. Although embodiments of the invention were described in detail, it should be understood that various changes, replacements and modifications are possible without departing from the spirit and scope of the invention.

EXPLANATION OF REFERENCE SYMBOLS

[0114]

1, 2, 3	Rolling system
10	Distortion processing unit
20	Hot tandem rolling mill
25	Hot reversible rolling mill
30, 35	Profilometer

Claims

1. A distortion computation method, the method comprising:

detecting a profile of a steel sheet rolled by a rolling mill;
computing from the detected profile second distortion indicating distortion appearing in an undulation on a surface of the steel sheet that constitutes deviation from a desired value of the rolled steel sheet;
determining third distortion from correlation between a threshold value of the third distortion indicating distortion corresponding to internal stress of the rolled steel sheet and a wavelength of a rolling-direction component of a profile determined from the detected profile, and the wavelength of the rolling-direction component of the detected profile,
wherein the correlation is computed by buckling analysis from a boundary condition determined from the detected profile, thickness of the rolled steel sheet, width of the rolled steel sheet, tensile strength of the rolled steel sheet, and distribution pattern of the third distortion; and
adding the second distortion to the third distortion so as to compute first distortion indicating difference between distortion corresponding to stress applied to the steel sheet by the rolling mill and desired distortion of the steel sheet by the rolling.

2. The distortion computation method as set out in claim 1, wherein the distribution pattern of the third distortion is computed to be one selected from among patterns whose width-direction component from one end at a central region of the steel sheet to another end at an edge region of the steel sheet is linear, a monotonic rising curve or a monotonic falling curve, a ridge pattern monotonically rising from the central region of the steel sheet and monotonically falling from near the edge region of the steel sheet, and a valley pattern monotonically falling from the central region of the steel sheet and monotonically rising from near the edge region of the steel sheet.

3. A distortion computation method as set out in claim 1, wherein the correlation is computed by buckling equations.

4. A distortion computation method as set out in claim 1 wherein the correlation is determined by a finite element method (FEM) and stored in memory in a table showing correspondence between the wavelength of the rolling-direction component of the detected profile and the threshold value of the third distortion.

5. The distortion computation method as set out in claim 1, further comprising sending a signal indicating the computed first distortion to the processing unit;
wherein the processing unit is controlled based on the computed first distortion to give the rolled steel sheet the desired profile.

6. The distortion computation method as set out in claim 5, further comprising detecting that an edge wave or a center buckle is formed over at least a half-wavelength.

7. A distortion computation method as set out in claim 5, wherein the processing unit is controlled to make the first distortion zero.

8. A rolling system, the system comprising:

a rolling mill for rolling a steel sheet;
a profilometer for detecting a profile of the steel sheet rolled by the rolling mill; and
a distortion processing unit for computing from the detected profile second distortion indicating distortion appearing in an undulation on a surface of the steel sheet that constitutes deviation from a desired value of the rolled steel sheet, and, in determining third distortion from correlation between a threshold value of the third distortion indicating distortion corresponding to internal stress of the rolled steel sheet and a wavelength of a rolling-direction component of a profile determined from the detected profile, and the wavelength of the rolling-direction component of the profile determined from the detected profile, computing the correlation by buckling analysis from a boundary condition determined by the detected profile, thickness of the rolled steel sheet, width of the rolled steel sheet, tensile strength of the rolled steel sheet, and distribution pattern of the third distortion, adding the second distortion to the third distortion so as to compute first distortion indicating difference between distortion corresponding to stress applied to the steel sheet by the rolling mill and desired distortion of the steel sheet by the rolling, and sending a signal indicating the computed first distortion to the rolling mill,
the rolling mill being controlled based on the computed first distortion to give the rolled steel sheet the desired profile.

Fig.1

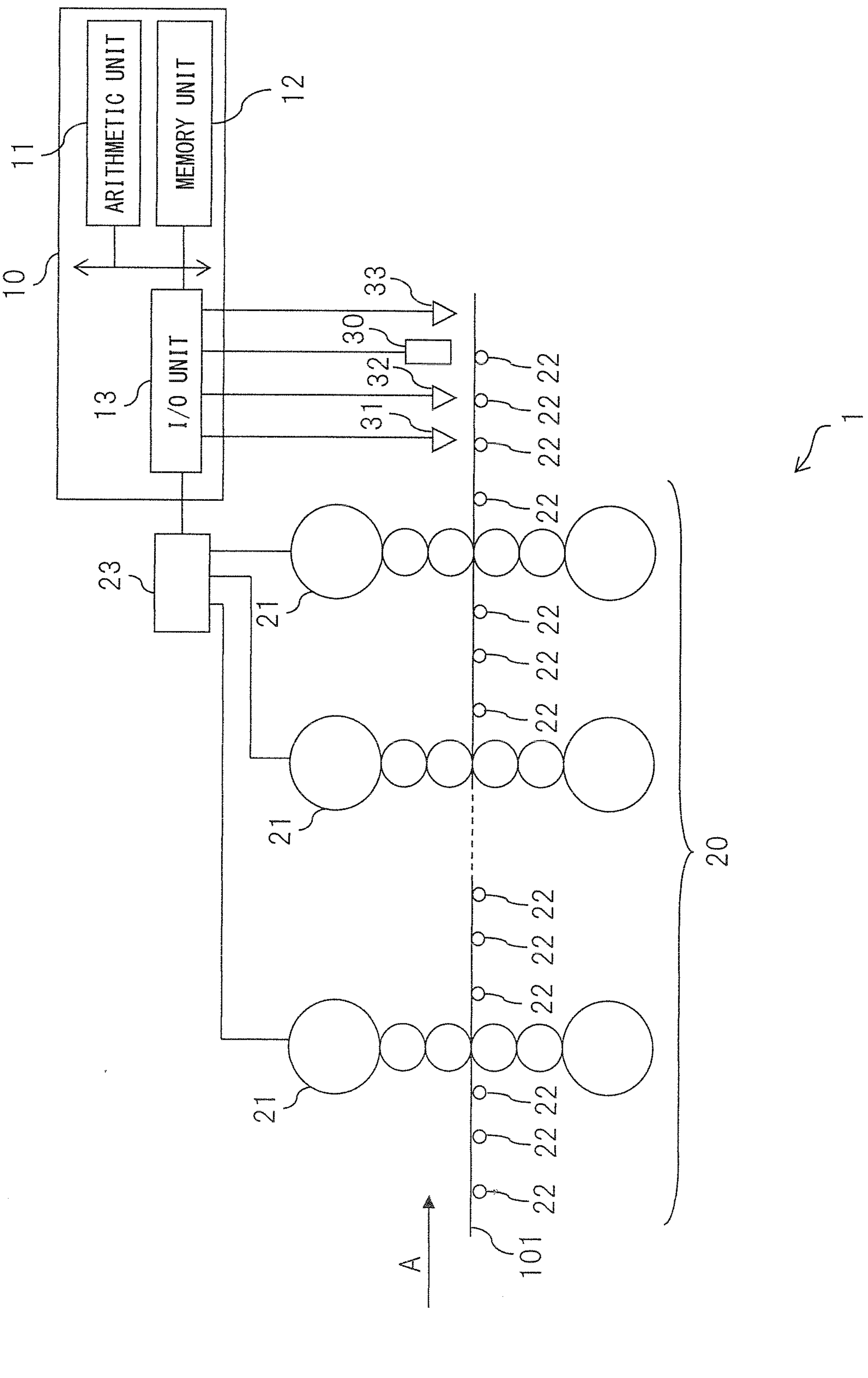

ARITHMETIC UNIT
MEMORY UNIT
I/O UNIT
10
11
12
13
1
20
21
22
23
30
31
32
33
101
A

Fig.2

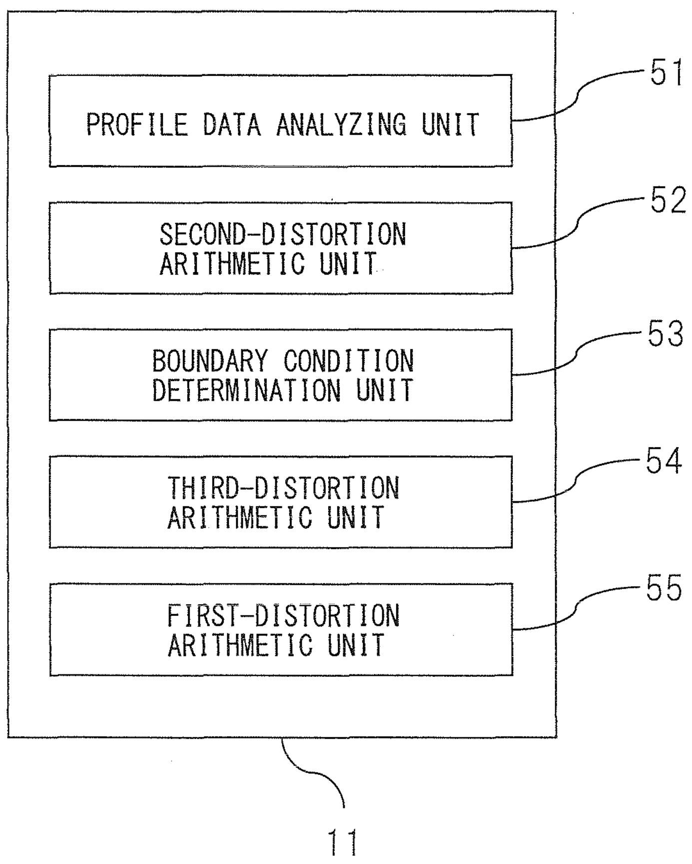

PROFILE DATA ANALYZING UNIT
51
SECOND-DISTORTION ARITHMETIC UNIT
52
BOUNDARY CONDITION DETERMINATION UNIT
53
THIRD-DISTORTION ARITHMETIC UNIT
54
FIRST-DISTORTION ARITHMETIC UNIT
55
11

Fig.3

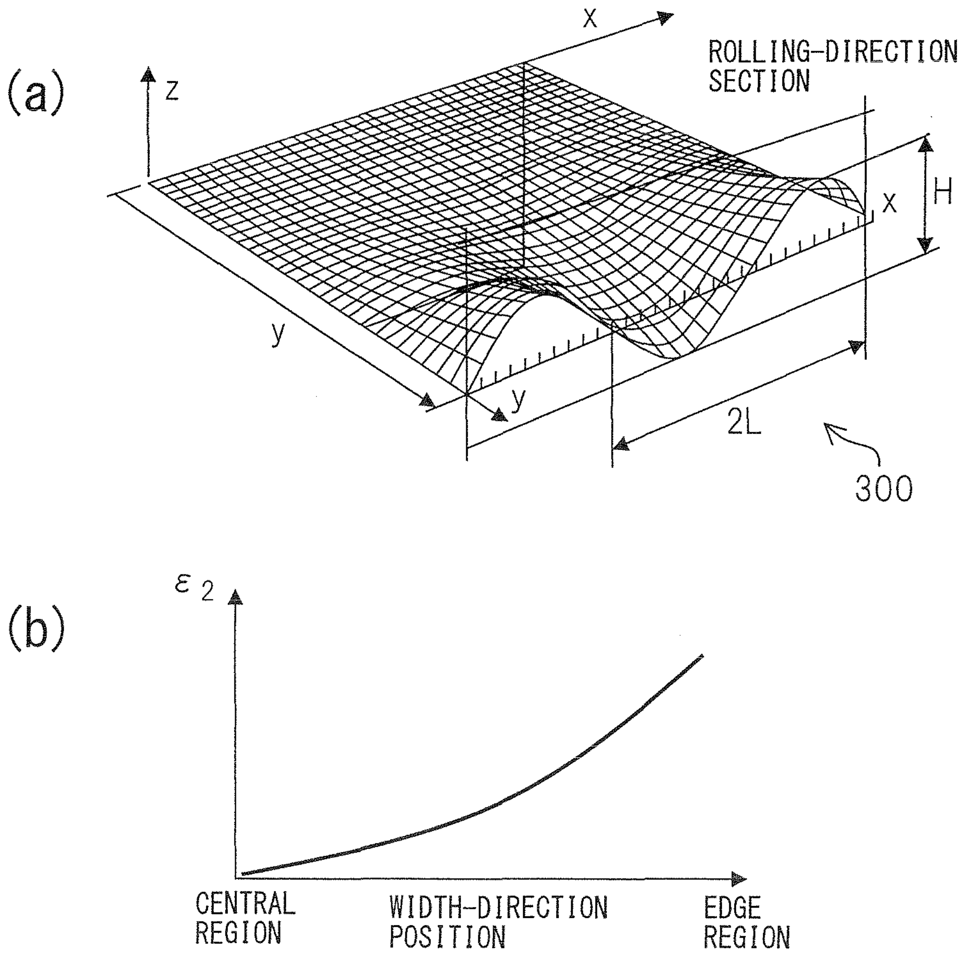

(a)
z
x
ROLLING-DIRECTION SECTION
H
x
y
y
2L
300
(b)
ε_2
CENTRAL REGION
WIDTH-DIRECTION POSITION
EDGE REGION

Fig.4

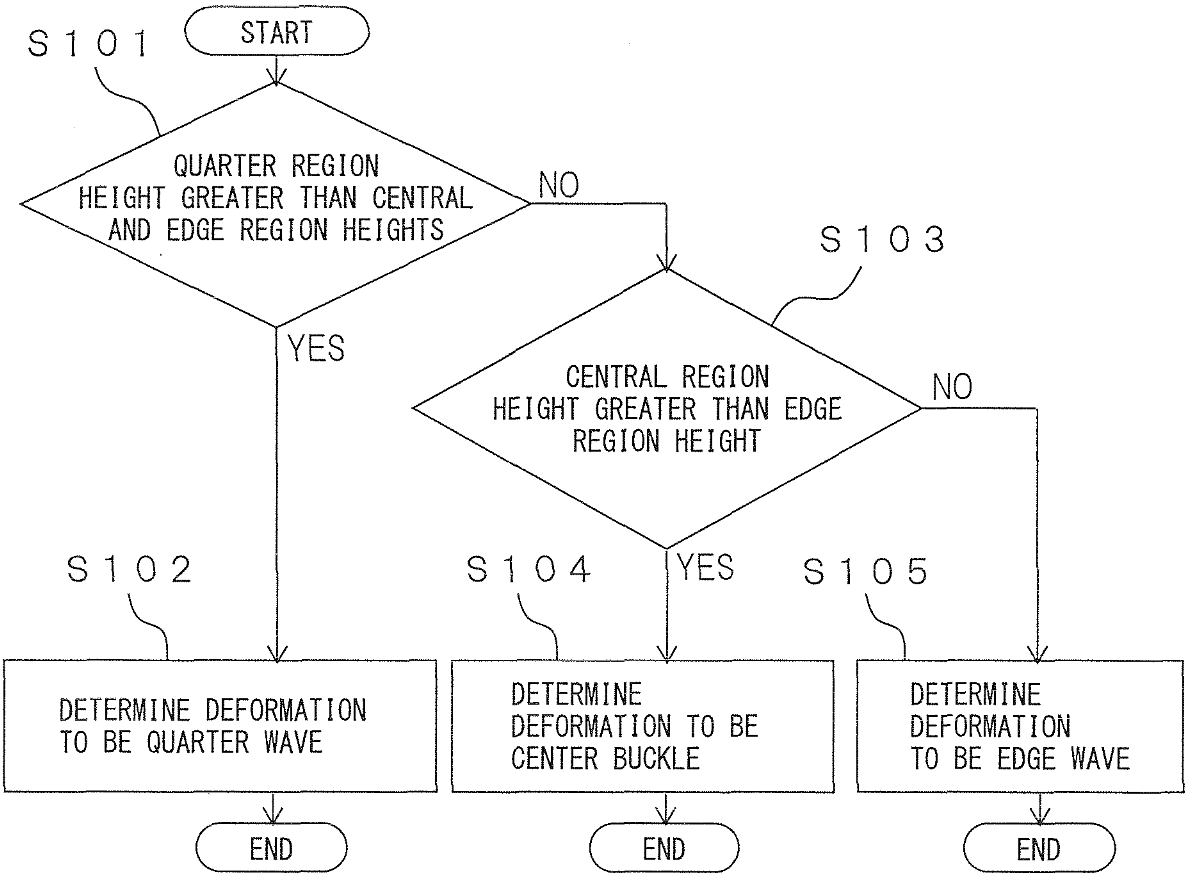

START
S101
QUARTER REGION HEIGHT GREATER THAN CENTRAL AND EDGE REGION HEIGHTS
NO
YES
S103
CENTRAL REGION HEIGHT GREATER THAN EDGE REGION HEIGHT
NO
YES
S102
DETERMINE DEFORMATION TO BE QUARTER WAVE
S104
DETERMINE DEFORMATION TO BE CENTER BUCKLE
S105
DETERMINE DEFORMATION TO BE EDGE WAVE
END
END
END

Fig.5

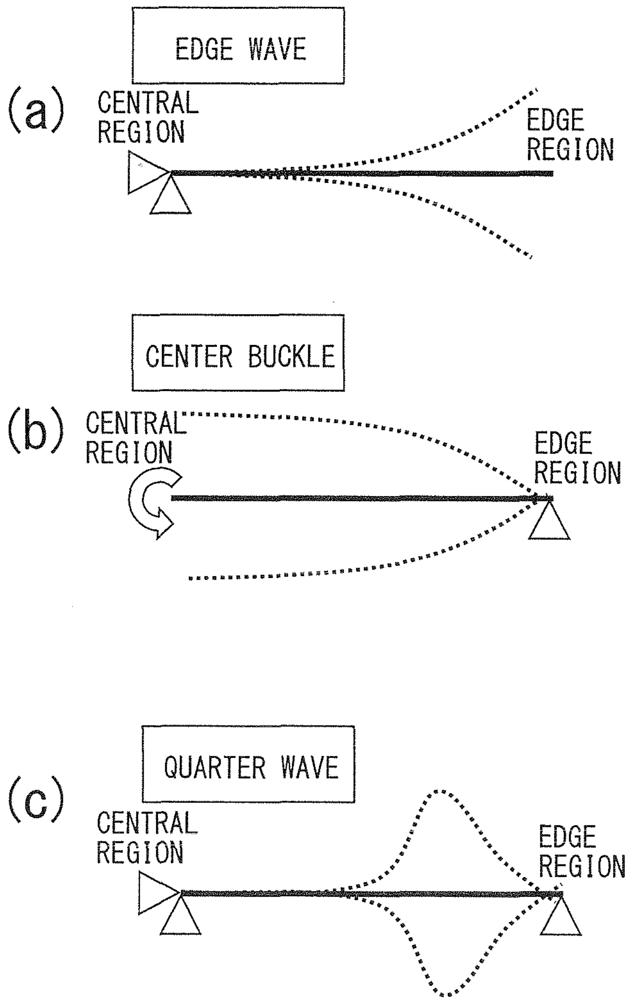

EDGE WAVE
(a)
CENTRAL
REGION
EDGE
REGION
CENTER BUCKLE
(b)
CENTRAL
REGION
EDGE
REGION
QUARTER WAVE
(c)
CENTRAL
REGION
EDGE
REGION

Fig.6

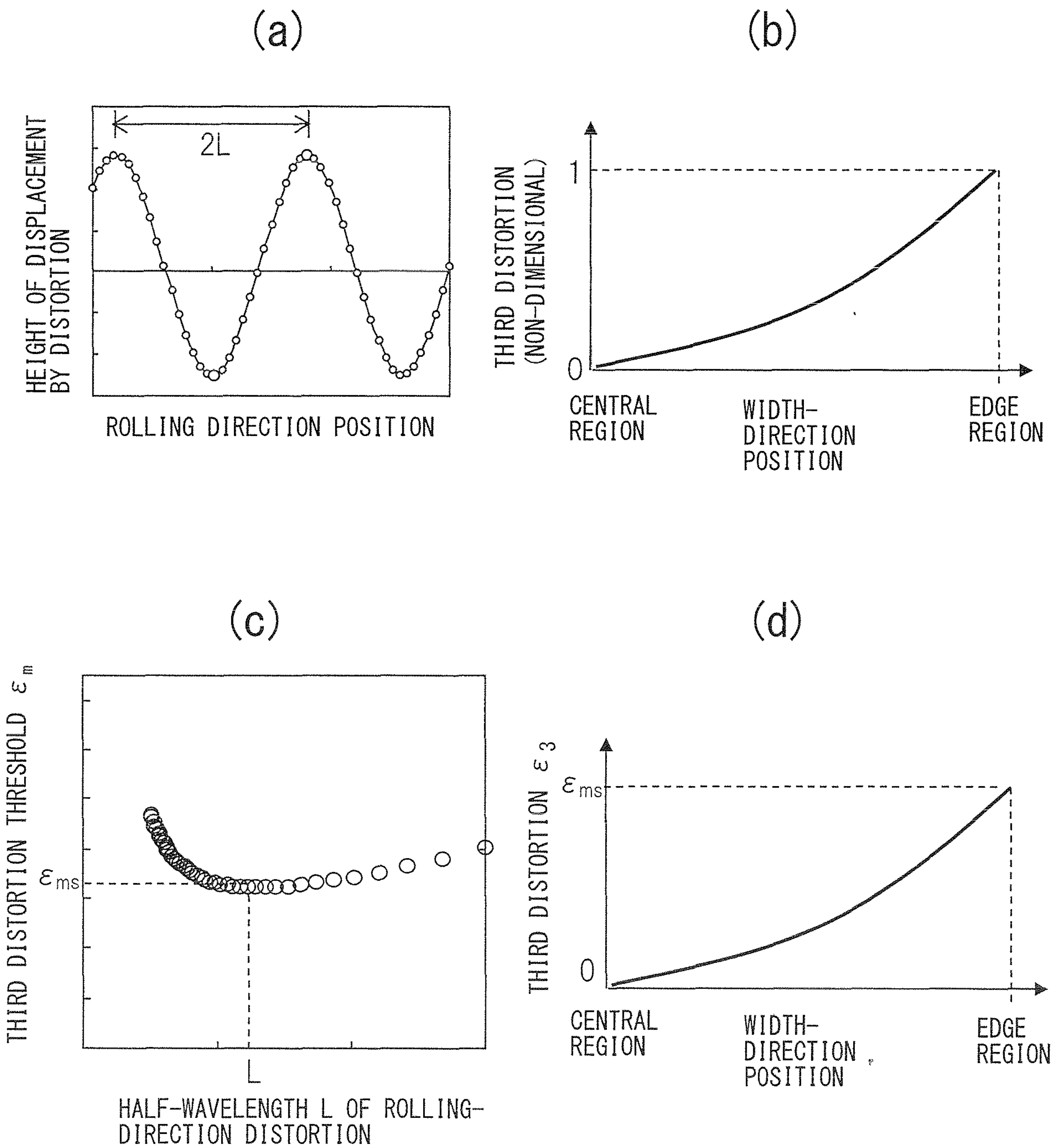

(a)
2L
HEIGHT OF DISPLACEMENT BY DISTORTION
ROLLING DIRECTION POSITION
(b)
THIRD DISTORTION (NON-DIMENSIONAL)
1
0
CENTRAL REGION
WIDTH-DIRECTION POSITION
EDGE REGION
(c)
THIRD DISTORTION THRESHOLD ε m
ε ms
L
HALF-WAVELENGTH L OF ROLLING-DIRECTION DISTORTION
(d)
THIRD DISTORTION ε 3
ε ms
0
CENTRAL REGION
WIDTH-DIRECTION POSITION
EDGE REGION

Fig.7

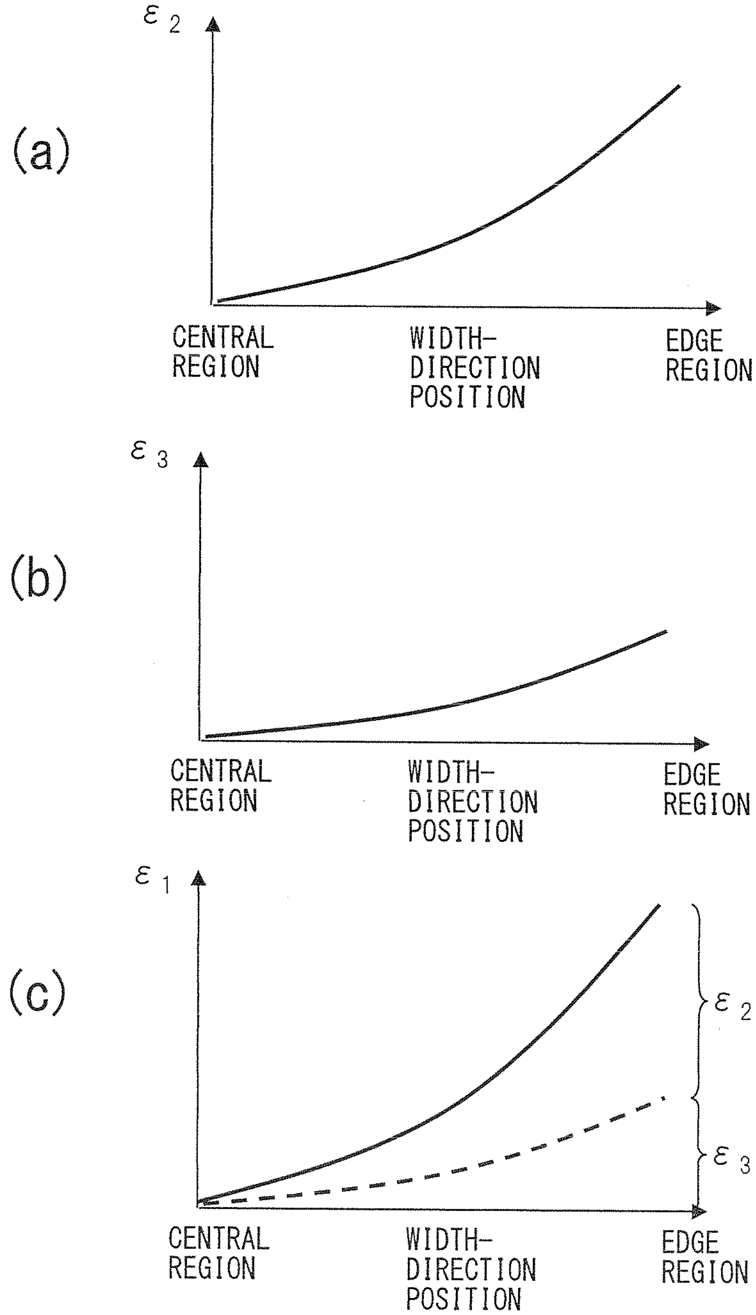

(a)
ε 2
CENTRAL REGION
WIDTH-DIRECTION POSITION
EDGE REGION
(b)
ε 3
CENTRAL REGION
WIDTH-DIRECTION POSITION
EDGE REGION
(c)
ε 1
ε 2
ε 3
CENTRAL REGION
WIDTH-DIRECTION POSITION
EDGE REGION

Fig.8

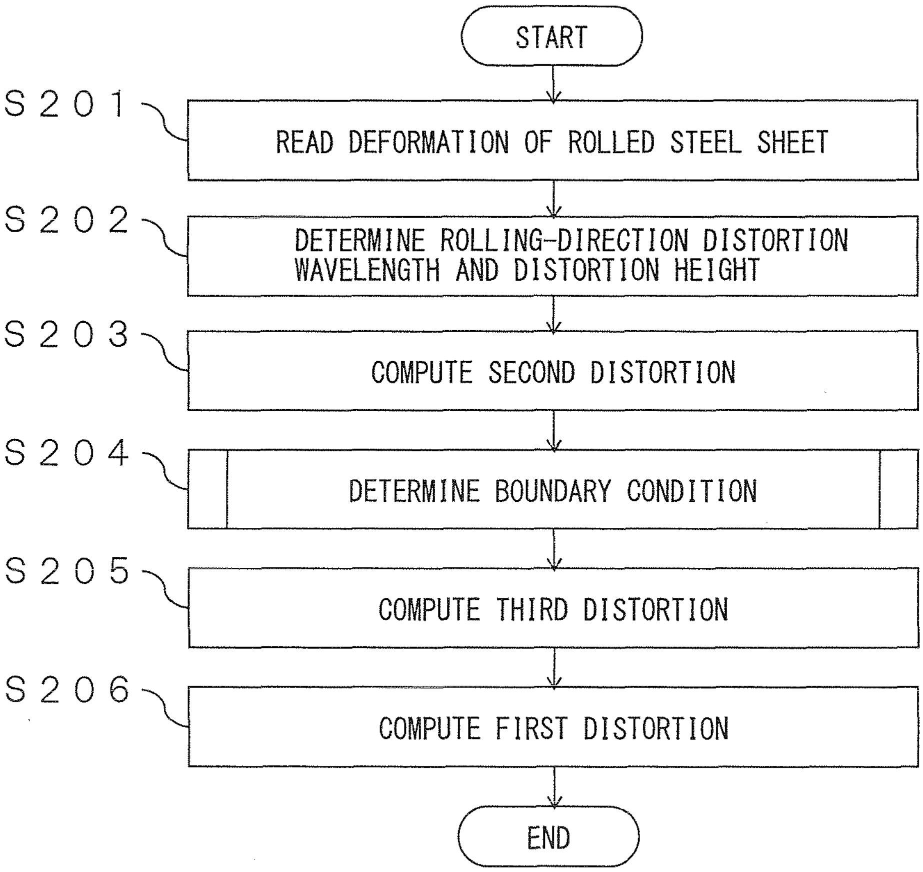

START
S201
READ DEFORMATION OF ROLLED STEEL SHEET
S202
DETERMINE ROLLING-DIRECTION DISTORTION WAVELENGTH AND DISTORTION HEIGHT
S203
COMPUTE SECOND DISTORTION
S204
DETERMINE BOUNDARY CONDITION
S205
COMPUTE THIRD DISTORTION
S206
COMPUTE FIRST DISTORTION
END

Fig.9

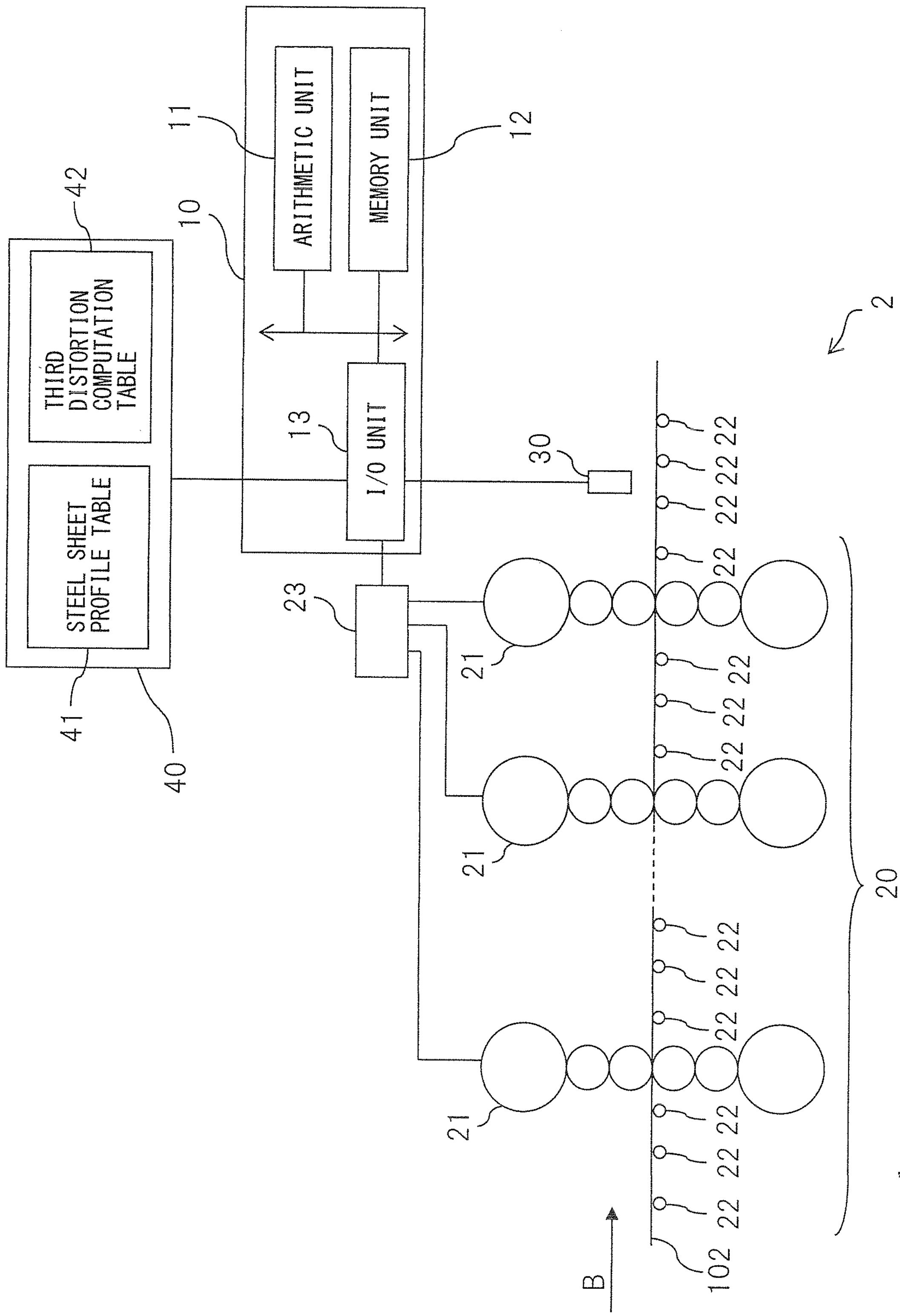

STEEL SHEET PROFILE TABLE
THIRD DISTORTION COMPUTATION TABLE
ARITHMETIC UNIT
MEMORY UNIT
I/O UNIT
40
41
42
10
11
12
13
23
30
21
21
21
22
20
2
102
B

Fig.10

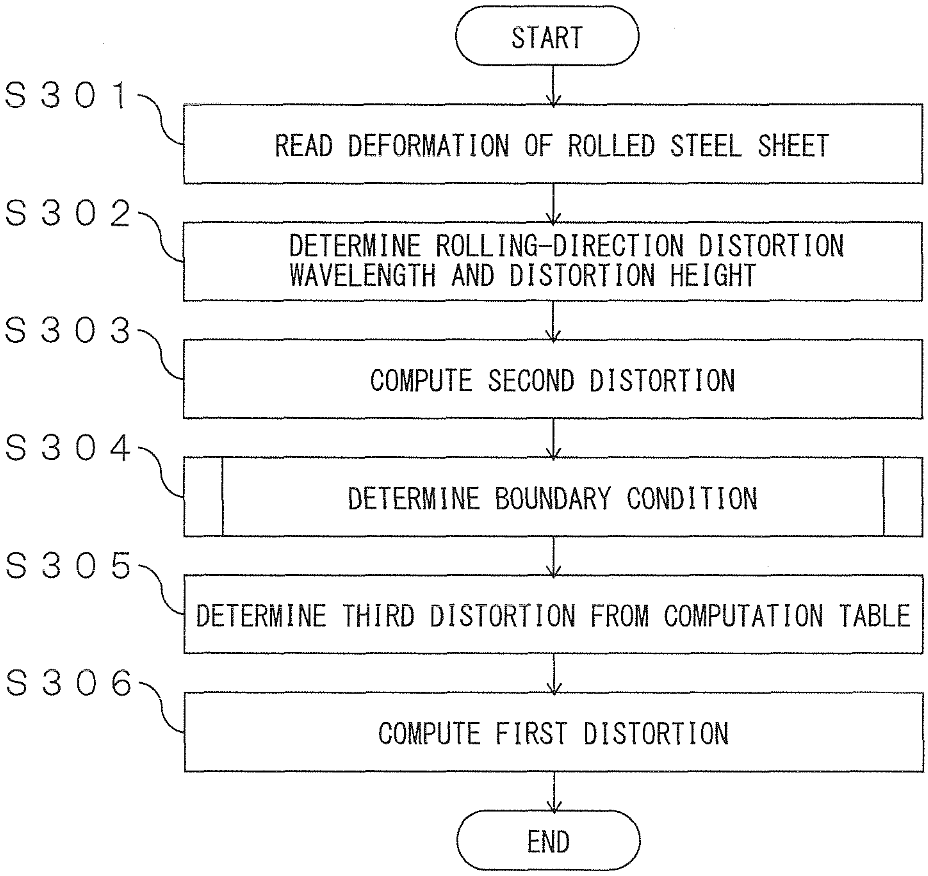

START
S301
READ DEFORMATION OF ROLLED STEEL SHEET
S302
DETERMINE ROLLING-DIRECTION DISTORTION WAVELENGTH AND DISTORTION HEIGHT
S303
COMPUTE SECOND DISTORTION
S304
DETERMINE BOUNDARY CONDITION
S305
DETERMINE THIRD DISTORTION FROM COMPUTATION TABLE
S306
COMPUTE FIRST DISTORTION
END

Fig.11

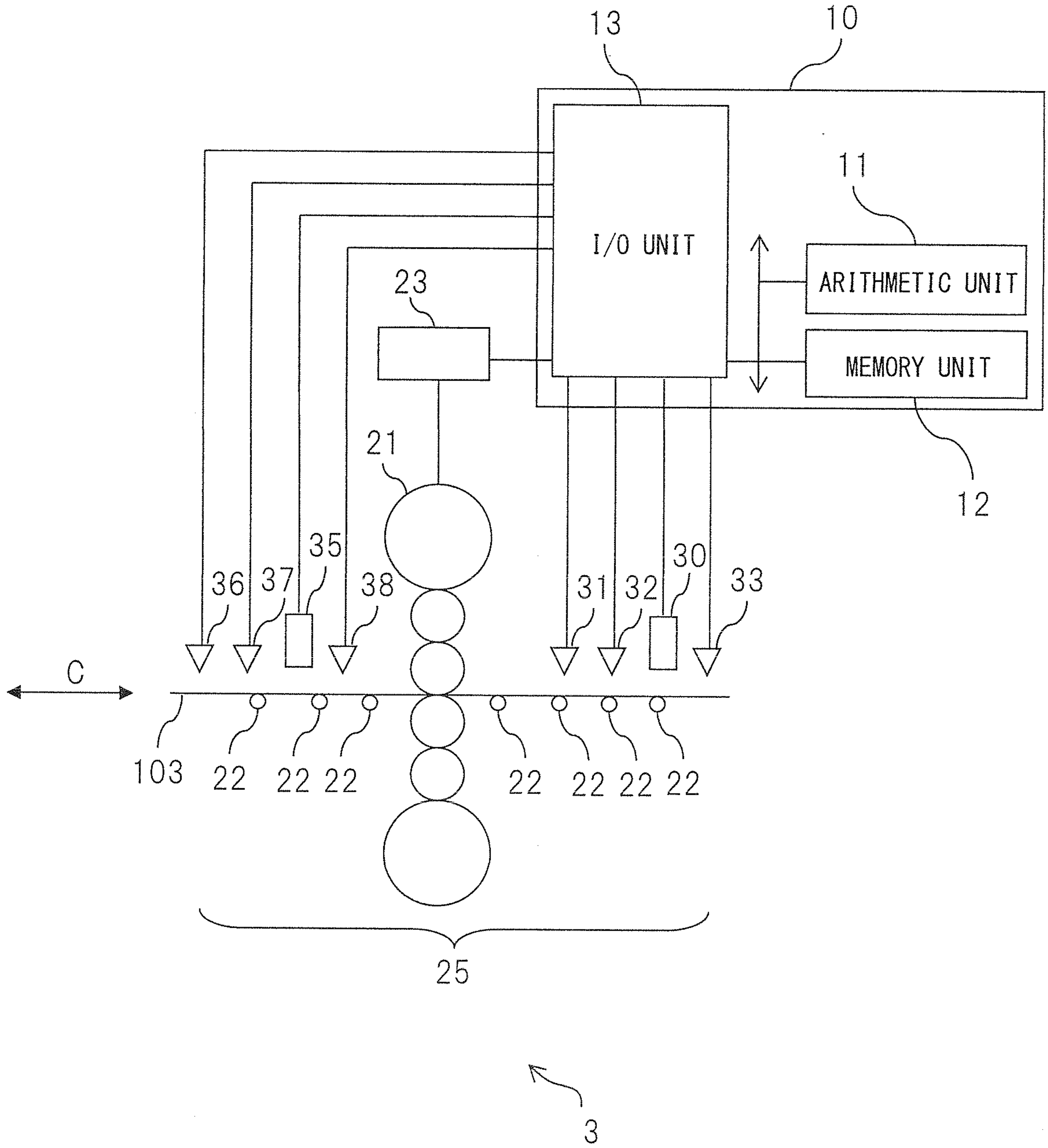
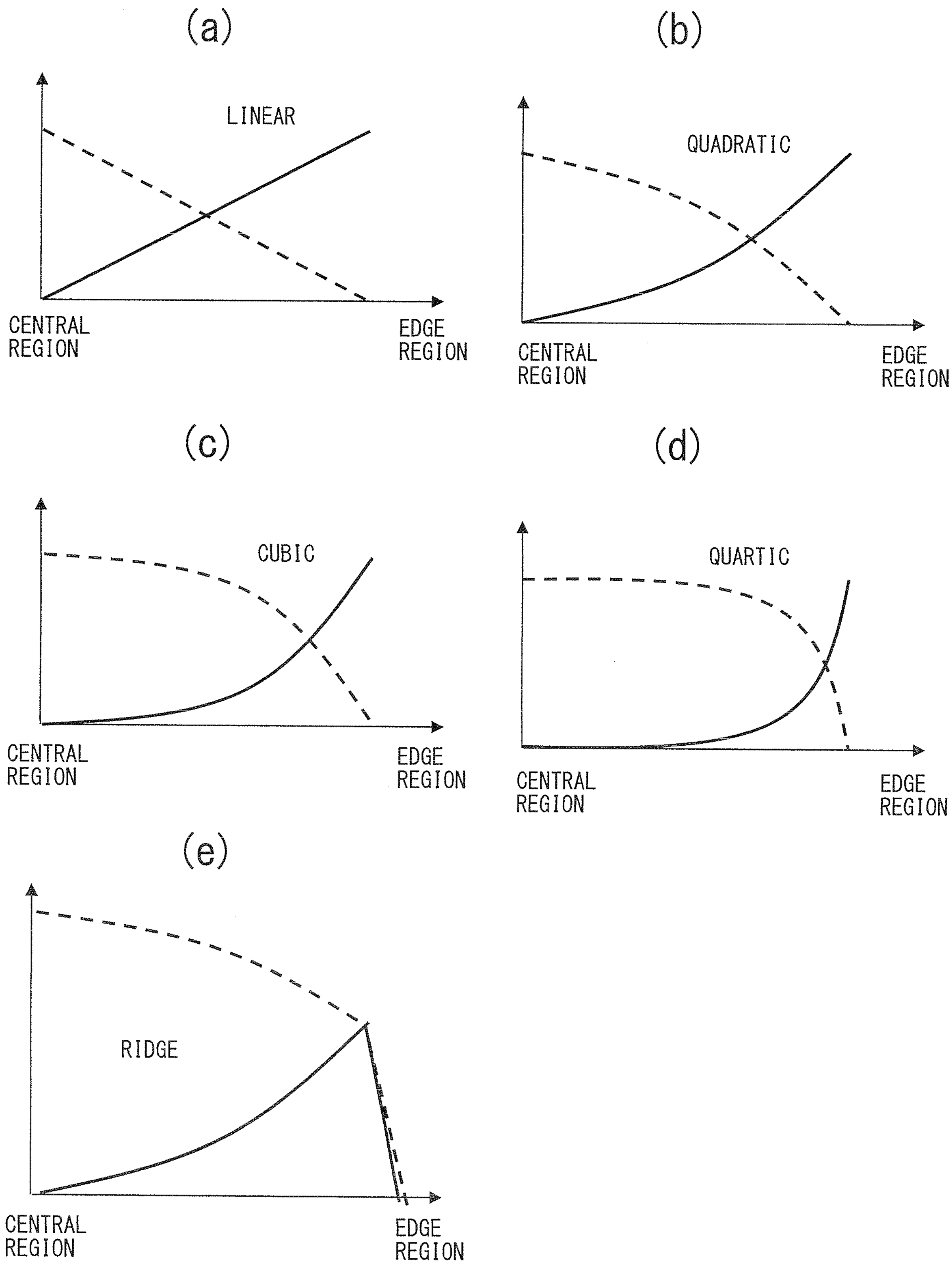

13
10
I/O UNIT
11
ARITHMETIC UNIT
MEMORY UNIT
12
23
21
35
30
36
37
38
31
32
33
C
103
22
22
22
22
22
22
22
25
3

Fig.12


(a)
LINEAR
CENTRAL REGION
EDGE REGION
(b)
QUADRATIC
CENTRAL REGION
EDGE REGION
(c)
CUBIC
CENTRAL REGION
EDGE REGION
(d)
QUARTIC
CENTRAL REGION
EDGE REGION
(e)
RIDGE
CENTRAL REGION
EDGE REGION

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/075706

A. CLASSIFICATION OF SUBJECT MATTER
B21C51/00(2006.01)i, *B21B38/02*(2006.01)i, *B21D1/00*(2006.01)i, *B21D1/05*(2006.01)i

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)
B21C51/00, B21B38/02, B21D1/00, B21D1/05

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

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.
A	JP 4262142 B2 (Nippon Steel Corp.), 13 May 2009 (13.05.2009), entire text; all drawings (Family: none)	1-8
A	JP 2001-252710 A (Nippon Steel Corp.), 18 September 2001 (18.09.2001), entire text; all drawings (Family: none)	1-8
A	JP 2007-507354 A (Siemens AG.), 29 March 2007 (29.03.2007), entire text; all drawings & US 2007/0006625 A1 & EP 1675694 A & WO 2005/035156 A1 & DE 10346274 A & CN 1863612 A	1-8

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

* Special categories of cited documents:
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"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 06 December, 2012 (06.12.12)	Date of mailing of the international search report 18 December, 2012 (18.12.12)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/075706

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 11-169939 A (Kobe Steel, Ltd.), 29 June 1999 (29.06.1999), entire text; all drawings (Family: none)	1-8

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REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- Buckling Analysis of Edge Waves and Middle Waves of Cold Rolled Sheet. *Journal of the Japan Society for Technology of Plasticity: Plasticity and Forming,* January 1987, vol. 28 (312), 58-66 **[0009]**