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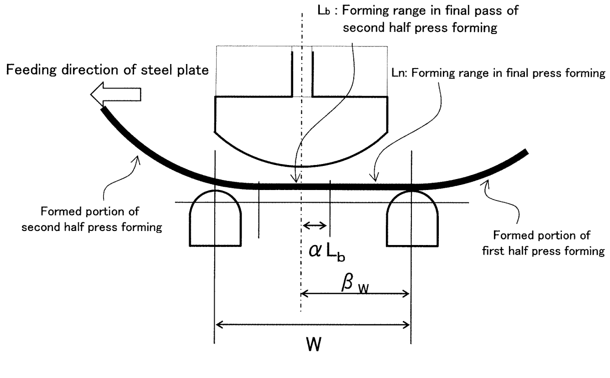
(54) **METHOD FOR PRODUCING WELDED STEEL PIPE**

(57) In a method of manufacturing a welded steel pipe using a press bending method of performing three-point bending press forming on a raw material steel plate by a pair of dies disposed in a steel plate feeding direction at a predetermined gap, and a punch configured to press the steel plate between the pair of dies to form an open pipe and then welding the open pipe to manufacture a steel pipe, when the open pipe is formed such that after performing first half press forming from one width end portion of the steel plate toward a width center (provided, leaving the width center unpressed), second half press forming is performed from a width end portion of an opposite side toward the width center (provided, leaving the width center unpressed), and the width center is finally subjected to final press forming to form an open pipe, the steel pipe supported on the dies of the steel plate width center side is assumed to be a non-formed portion in a final pass of the second half press forming, thereby manufacturing the open pipe in which the amount of offset of a welded part is small.

【Fig.6】



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Description

Technical Field

[0001] The present invention relates to a method of manufacturing a thick welded steel pipe having a large diameter used for a line pipe or the like, and more particularly, to a method of manufacturing an open pipe having high roundness by a press bending method for performing three-point bending press forming multiple times. In addition, in the present invention, the above-described open pipe (open seam pipe) refers to a formed article of a state in which plate end portions (open seam edges) facing each other are not welded after a plate material as a material is formed into a cylindrical shape.

Background Art

[0002] As the thick steel pipe having a large diameter used for a line pipe or the like, a so-called "UOE steel pipe" has been widely used. The UOE steel pipe is formed so that a steel plate having a predetermined width, length, and thickness is press-formed into a U-shape and then is press-formed into an O-shape to obtain an open pipe, and thereafter, a steel pipe is obtained by performing butt welding of the open pipe, and the diameter thereof is expanded (the pipe is expanded) to improve the roundness. However, in manufacturing the UOE steel pipe, the press forming of the steel plate into a U-shape and an O-shape requires a great pressure, and it is necessary to use a large-scale press machine.

[0003] Therefore, as a technique of reducing a pressing pressure when manufacturing the thick steel pipe having a large diameter, a method of manufacturing a steel pipe using a press bending method has been put into practical use, for example. According to such a method, after the application of bending (so-called end bending (edge crimping)) to an end portion in a width direction of a steel plate, a three-point bending press is performed multiple times while feeding the steel plate by a predetermined amount in the width direction to form the steel plate into a substantially circular open pipe, the butt welding is performed on an opening portion of the open pipe, and then, the steel pipe is obtained by correcting the shape.

[0004] However, in the above-described press bending method, since the press forming in the width direction of the steel plate is separately performed, a difference is liable to occur in the bent shape due to a slight variation of the thickness or strength of the steel plate. As a result, when butting the open pipe, a stepped portion (called "offset") is generated in the butted part, which may cause offset of the welded part. The offset of the welded part causes local concentration of tensile stress in the circumferential direction caused by the internal pressure, which may significantly damage reliability of the product.

[0005] In order to prevent offset of the welded part, there is a need to delicately adjust a press condition (for example, an amount of press-down) in a steel plate width direction, which has become an obstacle at the time of automation and mass production. Furthermore, when the offset has occurred in the welded part, the right and left butted parts has been welded by being restrained. When the steel plate is a high strength material or a thick material, there is a need for great restraining force, and then there is also a problem of limitation on an allowable range of manufacturing the steel plate.

[0006] As a technique coping with such problems, for example, Patent Literature 1 discloses a press-forming die in which a punch forming an upper die, a cradle having a fixed installation position to face the punch and becoming a bottom dead center of the punch, and the first and the second dies disposed to face each other on both right and left sides with the cradle interposed therebetween and capable of reciprocating in opposite directions are provided, and the cradle, the first die, and the second die constitute a lower die. Furthermore, Patent Literature 2 discloses a technique in which a concave surface of a radius corresponding to an outer diameter is formed in an outer die in a predetermined length, a convex surface of a radius corresponding to an inner diameter is formed in an inner die in a predetermined length, the outer die and the inner die are brought into close-contact with each other, a corresponding portion for pressing is bent between both dies, the inner die is brought into close-contact with the outer die in the state of receiving the steel plate at a position projecting inward from an extended surface of the outer die by roller members installed on both outer sides of the outer die, and the vicinity of the corresponding portion for pressing is made to become a bent state, thereby accurately performing the bending. Furthermore, Patent Literature 3 discloses a method of manufacturing a round steel pipe in which the steel plate is press-formed and bent, a portion of a groove is butted, welded and bonded to form an intermediate round steel pipe, and after the entire intermediate round steel pipe is heated, the surface of the intermediate pipe is allowed to pass between a plurality of forming rolls having a semicircular shape corresponding to a final radius and is subjected to hot-forming for adjusting the shape.

Citation List

Patent Literatures

[0007]

Patent Literature 1: JP 11-129031 A
Patent Literature 2: JP 2007-090406 A
Patent Literature 3: JP 2005-324255 A

Summary of Invention

Technical Problem

[0008] However, in the method described in Patent Literature 1, a plate thickness decreases, because the steel plate is clamped by the punch and the cradle in the bottom dead center. For that reason, when the clamped range is local, the pipe thickness becomes uneven and there is a possibility that a predetermined dimension is not satisfied. In method described in Patent Literature 2, the problems of Patent Literature 1 are solved by clamping the entire bent range by the outer die and the inner die, but since appropriate inner die and outer die dimensions differ depending on a diameter and a thickness of the steel pipe, there is a need to prepare the dies of various dimensions, and frequency of the die replacement increases, and thus there is a problem of poor productivity. In the method described in Patent Literature 3, there is a need for a heating process for performing the hot shape correction, which leads to a significant increase in the manufacturing cost. Furthermore, in a case where a steel plate produced by thermo-mechanical treatment is used for the material, there is a risk of damage to strength, toughness, and weldability due to heating.

[0009] The present invention has been made in view of the above-described problems of the related art, and an object thereof is to provide a method of manufacturing a welded steel pipe capable of simply manufacturing an open pipe having a small amount of offset of a welded part by a press bending method. Solution to Problem

[0010] In order to reduce the occurrence of offset of the welded part as much as possible, the inventors conducted a detailed investigation by paying attention to a change in the steel plate shape in the three-point bending press forming. As a result, in a method of manufacturing an open pipe in which after performing multiple press forming (first half press forming) toward a width center from one width end portion of a steel plate, multiple press forming (second half press forming) toward the width center from the opposite end portion is performed, and finally, the width central portion is subjected to the press forming, the followings have been found. In a final pass of the first half press forming, when the steel plate is set on dies, one die comes into contact with the non-formed steel plate, and the other die comes into contact with the already-formed steel plate. On the contrary, in a final pass of the second half press forming, depending on a feed length of the steel plate to be set, both dies come into contact with the already-formed steel plate. In such a case, a difference occurs in the processed shape between the first half press forming and the second half press forming, and great offset occurs in the butted part of the open pipe. Accordingly, it has been found that in order to prevent the above-described offset, it is necessary to locate the non-formed steel plate on the plate width center side in the final pass of the second half press forming, which has led to the development of the present invention.

[0011] That is, according to the present invention, there is provided a method of manufacturing a welded steel pipe, the method including: performing three-point bending press forming on a raw material steel plate by a pair of dies disposed in a steel plate feeding direction at a predetermined gap, and a punch configured to press the steel plate between the pair of dies to form an open pipe; and welding the open pipe, wherein, when the open pipe is formed such that after performing first half press forming from one width end portion of the steel plate toward a width center (provided, leaving the width center unpressed), second half press forming is performed from a width end portion of an opposite side toward the width center (provided, leaving the width center unpressed), and the width center is finally subjected to final press forming, the steel pipe, supported on the dies of the steel plate width center side, is assumed to be a non-formed portion in a final pass of the second half press forming.

[0012] In the method of manufacturing a welded steel pipe, the final pass of the second half press forming satisfies the following Formula (1):

$$\beta_b \cdot W < \alpha_b \cdot L_b + L_n \ldots(1)$$

where, L_b represents forming range (mm) in the final pass of the second half press forming,
L_n represents forming range (mm) in the final press forming,

W represents die gap (mm),
α_b represents shift ratio (-) of steel plate position in the final pass of the second half press forming, and
β_b represents shift ratio (-) of die position in the final pass of the second half press forming.

Advantageous Effects of Invention

[0013] According to the present invention, it is possible to obtain an open pipe free from stepped portion (offset) of the butted part, without causing adverse effects on the quality such as reduction in the thickness of the steel plate due to clamping between the lower die and the upper die, without a decline in working efficiency due to replacement of the lower die, and without necessity to change the forming conditions in the press forming of the first and second halves. Furthermore, according to the present invention, there is no need for a hot shape correction, and then it is possible to provide a steel pipe while maintaining manufacturing properties at a manufacturing stage of the raw material steel plate.

Brief Description of Drawings

[0014]

Fig. 1 is a schematic diagram illustrating a method of manufacturing an open pipe of the present invention.
Figs. 2(a) to 2(c) are schematic diagrams illustrating a final pass of first half press forming.
Figs. 3(a) to 3(c) are schematic diagrams illustrating a final pass of second half press forming when a feed length of a steel plate is relatively larger than a die gap.
Figs. 4(a) to 4(c) are schematic diagrams illustrating the final pass of the second half press forming when the feed length of the steel plate is relatively smaller than the die gap.
Fig. 5 is a schematic diagram illustrating steel plate feeding in the final pass of the second half press forming when the feed length of the steel plate is relatively smaller than the die gap.
Fig. 6 is a diagram illustrating a positional relation among a steel plate, a die, and a punch when the steel plate is disposed in a state prior to the final pass of the second half press forming.
Fig. 7 is a diagram illustrating an influence of a die gap W on a capacity required for three-point bending press forming.
Fig. 8 is a diagram illustrating an amount of offset of butted parts of the open pipe.

Description of Embodiments

[0015] Hereinafter, embodiments of the present invention will be specifically described.

[0016] Fig. 1 schematically illustrates a process of forming an open pipe before welding of the steel pipe, by a press bending method using a three-point bending press forming machine that has a pair of dies which is disposed in a steel plate feeding direction at a predetermined interval and supports the steel plate at two locations, and a punch which presses the portion of steel plate between the dies. In Fig. 1, the steel plate with the bent end is used, but the same in the case of no bent end in the steel plate.

[0017] First, as the first half press forming, the three-point bending press forming and the feeding of the steel plate are repeated multiple times (a times) toward position C from position A of Fig. 1 to form half of the steel plate into a substantially circular shape. At this time, the steel plate central position C is not formed, and the first half press forming is completed. In this specification, this process is referred to as "first half press forming".

[0018] Next, the three-point bending press forming and the feeding are repeated multiple times (b times) toward position C from position B as the other end of the steel plate to form the remaining half into a substantially circular shape. In the second half press forming, it is preferred that the forming conditions such as the feed length of the steel plate and the number of presses (number of passes) be the same as the first half press forming, in order to make the shape of the formed part the same as that of the first half press forming. In the second half press forming, the steel plate central position C is not formed, either. This process is referred to as "second half press forming". The steel plate after the second half press forming is formed in a C shape in which a flat portion remains in the width central part and the butted parts are greatly opened.

[0019] Finally, the flat portion of the raw material steel plate width central part is subjected to three-point bending press forming, and opening of the butted parts is closed. This process is referred to as "final press forming".

[0020] An amount of press-down (positional relation between the die and the punch) in the first half press forming and the second half press forming can be arbitrarily selected for each pass of the press forming to control the formed shape. In order to obtain the same formed shape in the first half press forming and the second half press forming, it is preferred that the amount of press-down be constant. However, when it is known that the end bending shape, the plate thickness, the plate strength and the like differ between the first half press bending side and the second half press bending side, or when an asymmetric shape is desired in consideration of the subsequent processes, the feed length of the steel plate, the number of presses, the amount of press-down and the like are changed for the first half press forming and the second half press forming. In that case, it is preferred that the changes at that location easily adjust the amount of press-down.

[0021] In addition, it is preferred that the feed length of the steel plate per each pass of the steel plate be equal to or less than the die gap. This is because when the feed length exceeds the die gap, the non-formed portion remains on the steel plate after forming, which results in a remarkable degradation of roundness of the open pipe and the product steel pipe.

[0022] Figs. 2(a) to 2(c) are schematic diagrams illustrating a final pass (a-th time) of the first half press forming. When the feeding of the steel plate is completed, the left die of Figs. 2(a) to 2(c) is in contact with the steel plate that is not yet formed. The already-formed steel plate portion having a curvature comes to the other right die, and portion of the steel plate is located above the die. For that reason, when pressing down the steel plate by the punch, the already-formed side having the curvature moves downwards, and the press forming starts to be performed on the steel plate from the state in which the steel plate is tilted. Furthermore, since there is offset between the right side and the left side at the time of the start of the press forming, and the already-formed side is greatly drawn during press, the forming area of the steel plate at the punch bottom dead center becomes asymmetrical with respect to the center of the upper die.

[0023] Meanwhile, Figs. 3(a) to 4(c) are schematic diagrams illustrating the final pass (b-th time) of the second half press forming. In the second half press forming, the formed shape greatly changes by the relative proportion between the die gap and the feed length of steel plate. For example, as illustrated in Figs. 3(a) to 3(c), when the feed length of the steel plate is relatively larger than the die gap, the right die in Figs. 3(a) to 3(c) comes into contact with the non-formed part on the center side in the width direction of the steel plate, but the already-formed steel plate portion having the curvature comes to the other left die, the steel pipe becomes located above the dies. That is, Figs. 3(a) to 4(c) shows a similar state to the above-described Figs. 2(a) to 2(c) though the right and left sides are reversed.

[0024] In contrast, as illustrated in Figs. 4(a) to 4(c), when the feed length of the steel plate is relatively smaller than the die gap, since the steel plate portion machined in the first half press forming also comes to the right die of Figs. 4(a) to 4(c), both right and left dies come into contact with the already-formed portion. For comparison, in Figs. 4(a) to 4(c), the steel plate position of Figs. 2(a) to 2(c) is horizontally inverted and indicated by broken lines. An amount of slope of the steel plate at the time of start of the press forming (Fig. 4(b)) is less than that of Figs. 2(a) to 2(c), and a deformation region in the punch bottom dead center (Figs. 4(a) to 4(c)) is different from that of Figs. 2(a)to 2(c). For this reason, a difference occurs between the right and left shapes.

[0025] Besides, in the case of Figs. 4(a) to 4(c), in addition to the difference in shape at the time of the punch bottom dead center, a difference occurs in the shape after forming in the same amount of press-down as the first half press forming, since the punch position when starting the press forming is not the same as the cases of Figs. 2(a) to 3(c).

[0026] Furthermore, in the case of Figs. 4(a) to 4(c), the shape of the right portion of the steel plate is different from the shape of the left portion of the steel plate of Figs. 3(a) to 3(c). In the case of setting the steel plate position by a device (such as a guide) for feeding the steel plate disposed on the machine side of the press machine, for example, the set position of the steel plate is shifted even at the same guide position as that of the first half press forming as illustrated in Figs. 3(a) to 3(c), which leads to differences in formed shape.

[0027] Fig. 5 schematically illustrates a situation of feeding the steel plate for the final pass of the second half press forming, in a case where the same feed length of the steel plate as Figs. 4(a) to 4(c) is relatively smaller than the die gap. In order to feed the steel plate to the position of the final pass, the steel plate is fed toward a steel plate width end portion side (a left side of Fig. 5). However, before reaching the final pass position, the center of gravity of the steel plate exceeds the right die of Fig. 5 of the width center side of the steel plate, and then the steel plate width end portion side of the left side moves downwards and comes into contact with the left die. The position where the left end portion of the steel plate starts to move downwards and the position coming into contact with the die depend on inertia force when feeding the steel plate and frictional resistance between the die and the steel plate due to differences in the surface conditions of the steel plate, which causes the variation in the range of press forming.

[0028] As described above, when the feed length of the steel plate is relatively smaller than the die gap, as illustrated in Figs. 4(a) to 4(c), the ranges of the deformation in the final pass are different between the first half press forming and the second half press forming, and as illustrated in Fig. 5, a posture of a forming target material when feeding the steel plate becomes unstable. For this reason, a difference occurs in the steel plate shape after press forming on the right and left sides.

[0029] Therefore, the inventors examined the press conditions for preventing the steel plate from becoming the state illustrated in Figs. 4(a) to 4(c) in the second half press forming.

[0030] Fig. 6 illustrates a positional relation among the steel plate, the die, and the punch when disposing the steel plate in a state prior to the final pass (b-th time) of the second half press forming. Here, symbols L_b, L_n, W, α_b, and β_b illustrated in Fig. 6 are defined as follows.

L_b: forming range in the final pass of the second half press forming (mm)
L_n: forming range in the final press forming (mm)

W: die gap (mm)
α_b: shift ratio of the steel plate position in the final pass of the second half press forming (-)
β_b: shift ratio of the die position in the final pass of the second half press forming (-)

[0031] Here, there are relations of $0 \le \alpha \le 1,0 \le \beta \le 1$. When α is 0.5, the center of L_b corresponds to the center of the punch, and when α is less than 0.5, the center of L_b is shifted to the left side from the center of the punch. When P is 0.5, the center between the dies corresponds to the center of the punch, and when β is less than 0.5, the center of the die is shifted to the left side from the center of the punch. In this case, after the final pass (b-th time) of the second half press forming, the feed length of the steel plate to the final forming (n-th time) becomes $\alpha_b \times L_b + L_n/2$.

[0032] As can be seen from Fig. 6, when the steel plate portion formed in the first half press forming comes into contact with the right die in Fig. 6, that is, when the steel plate portion becomes the same state as Figs. 2(a) to 2(c), the following condition is satisfied:

$$\beta_b \cdot W < \alpha_b \cdot L_b + L_n \ldots (1)$$

[0033] Here, when the center of the punch corresponds to the center of the die, and corresponds to the center of the steel plate forming range of the final pass, that is, when $\alpha = 0.5$, $\beta = 0.5$, the following Formula is obtained:

$$W < L_b + 2L_n \ldots (2)$$

Furthermore, in the case of $L_b = L_n$, that is, when $\alpha = 0.5$, $\beta = 0.5$, and the steel plate feed length is constant, the following Formula is obtained.

$$W < 3L_b \ldots (3)$$

This means that the steel plate feed length needs to be set to 1/3 or more of the die gap W.

[0034] Next, an influence of the die gap W on the capacity required for three-point bending press forming will be considered with reference to Fig. 7.

[0035] In the three-point bending forming, since a forming target material (steel plate) is deformed by yielding of the end portion of the forming range, bending moment necessary for plastic deformation of the forming target material needs to act on the end portion of the forming range. Here, the bending moment required for the plastic deformation is a value M_f which depends on the thickness of the forming target material and the deformation resistance. Meanwhile, the force acting on the forming target material from the die is reaction force P_1 and P_4 received from the dies, and moment obtained by multiplying the reaction force by distances (L_1, L_4, respectively) to the deformation point (the end portion of the forming range) acts. When one or more of $P_1 \times L_1$, and $P_4 \times L_4$ exceeds M_f, the deformation starts.

[0036] However, when the die gap is narrow, the distances L_1 and L_4 also decrease, and then the reaction forces P_1 and P_4 required for the deformation increase and exceed the capacity of the press machine, and this results in that the forming is not possible in this case. Therefore, the die gap of three-point bending press forming has a lower limit value defined from the capacity of the press machine, the dimension of the forming target material, and the strength.

[0037] In order to manufacture the steel pipe using the open pipe which is press-formed under the above-described pressing conditions, for example, after continuously tack-welding the open seam edges of the open pipe using a continuous tack-welding apparatus, permanent welding may be performed in the order of the inside welding and the outside welding. Next, in order to improve the roundness of the steel pipe, the steel pipe which has been subjected to the permanent welding is preferably expanded using a pipe expansion apparatus. The pipe expansion ratio (= (outer diameter of the pipe after pipe expansion - outer diameter of the pipe before pipe expansion) / outer diameter of the pipe before pipe expansion x 100 (%)) is normally within a range of 0.3 to 1.5%, but from the viewpoint of achieving a balance between the improvement effect of the roundness and capability required for the pipe expansion apparatus, the pipe expansion ratio is preferably within a range of 0.5 to 1.2%.

Example 1

[0038] After a thick steel plate having a width of 2755 mm, a length of 12192 mm, a thickness of 31.8 mm, and strength of API X80 Grade (performance tensile strength 759 to 778 MPa) is subjected to end face machining by an edge mirror into the plate width of 2745.3 mm, the range of 210 mm from the plate ends of both widths is subjected to end bending of a bending angle of 18° using a die of R 280 mm.

[0039] Next, the thick steel plate subjected to the above-described end bending is subjected to three-point bending press forming by a three-point press machine having the capacity of 100 MN while variously changing the steel plate feed length and the die gap, is formed into an open pipe having an outer diameter of 914.4 mm, a length of 12192 mm, and a pipe thickness of 31.8 mm, and an amount of offset of the butted part defined in Fig. 8 is measured. In addition, a punch outer peripheral surface of the three-point bending press forming is R 315 mm, and a die outer peripheral surface is R 100 mm.

[0040] Table 1 indicates measurement results of the amount of offset of the butted part in conjunction with the press conditions. In addition, as the press conditions, the number of passes of the second half press forming, a bend angle θ_b per pass, a forming range L_b in the final pass of the second half press forming, a forming range L_n in the final pass forming, a punch shift ratio α_b in the final pass of the second half press forming, a die shift ratio β_b, and a die gap W are indicated. In other passes of the second half press forming, the bend angle per pass, the forming range, the punch shift ratio, and the die shift ratio are the same as those of the final pass of the second half press forming. The number of presses and the conditions of the first half press forming are the same as those of the second half press forming.

[0041] Furthermore, "capacity shortage" described in a remark column of Table 1 indicates that the die gap is too narrow and it is not possible to perform the press forming due to the capacity shortage of the press machine. Meanwhile, under the conditions in which the press force is within the capability range, it indicates minimum values and maximum values of the amount of offset when forming the five open pipes manufactured under the same condition.

[0042] In the evaluation of the amount of offset of the butted parts illustrated in Table 1, from the viewpoint of the correction capability of a restrainer during tack welding installed in the production line of the welded steel pipe used in the present example, it is determined that the amount of offset of 5 mm or less is pass (O) and the amount of offset greater than 5 mm is failure (X).

[0043] From Table 1, it is understood that when the final pass of the second half press forming is performed under the condition of α_b = 0.5, and β_b = 0.5 and also satisfying the conditions of Formula (1) of the present invention, the amount of offset of the butted part is 5 mm or less, which is the correctable range for all examples. Meanwhile, under the conditions that do not satisfy the conditions of Formula (1), the amount of offset exceeding the correctable range occurs.

[Table 1]

№	Press condition							Evaluation index *			Amount of offset (mm)		Remarks
	Number of passes	θb (°)	Lb (mm)	Ln (mm)	αb	βb	W (mm)	Left side of formula (1)	Right side of formula (1)	Evaluation	Minimum	Maximum	
1	9	14.9	121	121	0.5	0.5	240	120	182	○	—		Capacity shortage
2							260	130	182	○	—		Capacity shortage
3							280	140	182	○	0.0	1.0	Invention Example
4							300	150	182	○	0.0	1.0	Invention Example
5							320	160	182	○	0.0	0.0	Invention Example
6							340	170	182	○	0.0	1.0	Invention Example
7							360	180	182	○	0.0	1.0	Invention Example
8							380	190	182	×	2.0	6.0	Invention Example
9							400	200	182	×	3.0	7.0	Invention Example
10							420	210	182	×	1.0	6.0	Invention Example
11	8	16.6	136	136	0.5	0.5	280	140	203	○	—		Capacity shortage
12							300	150	203	○	—		Capacity shortage
13							320	160	203	○	—		Capacity shortage
14							340	170	203	○	—		Capacity shortage
15							360	180	203	○	0.0	1.0	Invention Example
16							380	190	203	○	0.0	2.0	Invention Example
17							400	200	203	○	0.0	1.0	Invention Example
18							420	210	203	×	3.0	6.0	Invention Example
19							440	220	203	×	2.0	6.0	Invention Example
20							460	230	203	×	4.0	8.0	Invention Example
21	7	18.8	154	154	0.5	0.5	360	180	231	○	—		Capacity shortage
22							380	190	231	○	0.0	2.0	Invention Example
23							400	200	231	○	0.0	1.0	Invention Example
24							420	210	231	○	0.0	0.0	Invention Example
25							440	220	231	○	0.0	1.0	Invention Example
26							460	230	231	○	0.0	0.0	Invention Example
27							480	240	231	×	0.0	7.0	Comparative Example
28							500	250	231	×	2.0	7.0	Comparative Example
29							520	260	231	×	3.0	9.0	Comparative Example
30							540	270	231	×	5.0	10.0	Comparative Example
31	6	21.8	179	154	0.5	0.5	420	210	243	○	0.0	0.0	Invention Example
32							440	220	243	○	0.0	1.0	Invention Example
33							460	230	243	○	1.0	2.0	Invention Example
34							480	240	243	○	0.0	2.0	Invention Example
35							500	250	243	○	0.0	2.0	Invention Example
36							520	260	243	○	0.0	1.0	Invention Example
37							540	270	243	×	2.0	8.0	Comparative Example
38							560	280	243	×	3.0	10.0	Comparative Example
39							580	290	243	×	2.0	8.0	Comparative Example
40							600	300	243	×	5.0	11.0	Comparative Example
41	5	25.7	210	210	0.5	0.5	460	230	314	○	0.0	0.0	Invention Example
42							480	240	314	○	0.0	2.0	Invention Example
43							500	250	314	○	0.0	1.0	Invention Example
44							520	260	314	○	1.0	2.0	Invention Example
45							540	270	314	○	0.0	1.0	Invention Example
46							560	280	314	○	0.0	0.0	Invention Example
47							580	290	314	○	1.0	2.0	Invention Example
48							600	300	314	○	0.0	2.0	Invention Example
79							620	310	314	○	1.0	3.0	Invention Example
50							640	320	314	×	8.0	11.0	Comparative Example

* Formula (1): $\beta_b \cdot W < \alpha_b \cdot L_b/2 + L_n$

Example 2

[0044] In the same manner as Example 1, the thick steel plate having strength of API X80 Grade, an outer diameter of 914.4 mm, a length of 12192 mm, and a plate thickness of 31.8 mm is subjected to three-point bending press forming into an open pipe for a welded steel pipe. At this time, the number of passes of the second half press forming is changed to five times and nine times, the die gap is changed to 360 mm, 380 mm, 620 mm, and 640 mm, and the shift amounts α_b and β_b of the final pass in the second half press forming in each of the above-described conditions are variously changed. The bend angle per pass and the forming range of other passes of the second half press forming are the same as those of the final pass, and the punch shift ratio and the die shift ratio are 0.5. Furthermore, the number of presses and the conditions of the first half press forming are the same as those of the second half press forming.

[0045] The amount of offset of the welded part of each open pipe is measured and evaluated in the same manner as Example 1, and the results thereof are indicated in Table 2.

[0046] From Table 2, it is understood that when performing the final pass of the second half press forming under the conditions satisfying the conditions of Formula (1) of the present invention, the amount of offset of the welded part of the open pipe becomes a small value of the correctable range, regardless of the values of α_b and β_b. It is also understood that, even when the amount of offset is large, the amount of offset can be reduced to the correctable range, by changing α_b and β_b to suitable values satisfying the conditions of Formula (1) of the present invention.

[Table 2]

№	Press Condition							Evaluation index *			Amount of offset (mm)		Remarks
	Number of passes	θb (°)	Lb (mm)	Ln (mm)	αb	βb	W (mm)	Left side of formula (1)	Right side of formula (1)	Evaluation	Minimum	Maximum	
1					0.50			180	182	○	0.0	1.0	Invention Example
2					0.48		360	180	180	×	0.0	6.0	Comparative Example
3					0.46			180	177	×	3.0	6.0	Comparative Example
4	9	14.9	121	121	0.50	0.50		190	182	×	2.0	6.0	Comparative Example
5					0.56		380	190	189	×	0.0	7.0	Comparative Example
6					0.58			190	192	○	0.0	1.0	Invention Example
7					0.60			190	194	○	1.0	2.0	Invention Example
8						0.49		176	182	×	2.0	7.0	Comparative Example
9						0.50	280	180	182	○	0.0	1.0	Invention Example
10						0.51		184	182	○	1.0	2.0	Invention Example
11	9	14.9	121	121	0.50	0.52		187	182	○	0.0	2.0	Invention Example
12						0.47		179	182	○	1.0	2.0	Invention Example
13						0.48	360	182	182	×	1.0	6.0	Comparative Example
14						0.49		186	182	×	0.0	7.0	Comparative Example
15						0.50		190	182	×	2.0	6.0	Comparative Example
16					4			310	314	○	1.0	3.0	Invention Example
17					0.48		620	310	310	×	0.0	6.0	Comparative Example
18					0.46			310	306	×	2.0	9.0	Comparative Example
19	5	25.7	210	210	0.50	0.50		320	314	×	8.0	10.0	Comparative Example
20					0.52		640	320	319	×	1.0	8.0	Comparative Example
21					0.58			320	323	○	0.0	1.0	Invention Example
22					0.56			320	327	○	1.0	2.0	Invention Example
23						0.49		304	314	×	2.0	7.0	Comparative Example
24						0.50	620	310	314	○	1.0	3.0	Invention Example
25						0.51		316	314	○	1.0	2.0	Invention Example
26	5	25.7	210	210	0.50	0.52		322	314	○	0.0	2.0	Invention Example
27						0.47		301	314	○	1.0	2.0	Invention Example
28						0.48	640	307	314	○	1.0	2.0	Invention Example
29						0.49		314	314	×	0.0	7.0	Comparative Example
30						0.50		320	314	×	8.0	10.0	Comparative Example

* Formula (1): $\beta_b \cdot W < \alpha_b \cdot L_b/2 + L_n$

Example 3

[0047] In the same manner as Examples 1 and 2, the open pipe for a welded steel pipe having strength of API X80 Grade, an outer diameter of 914.4 mm, a length of 12192 mm, and a thickness of 31.8 mm is manufactured. At this time, the number of passes of the second half press forming is set to nine times, the die gap is set to 360 mm and 380 mm, and a forming range L_b of the final pass of the second half press forming and a forming range L_n of the final pass forming are variously changed as indicated in Table 3. Furthermore, a bend angle θ_b in the final pass of the second half press forming and a bend angle θ_n of the final press forming are also changed as indicated in Table 3. The bend angle per pass, and the forming range, the punch shift ratio, and the die shift ratio of other passes of the second half press forming are the same as those of the final pass of the second half press forming, and the number of presses and the conditions of the first half press forming are the same as those of the second half press forming.

[0048] The amount of offset of the welded part of each open pipe is measured and evaluated in the same manner as Example 1, and the results thereof are indicated in Table 3.

[0049] From Table 3, it is understood that when performing the three-point bending press forming under the conditions of Formula (1) of the present invention, the amount of offset of the welded part of the open pipe can be reduced to a value less than the correctable range, regardless of the magnitudes of the forming ranges L_b and L_n. In particular, it is understood that even when the number of passes of the second half press forming is reduced to five times, the amount of offset is suppressed to the correctable range, by increasing the forming range L_n of the final press forming.

[Table 3]

№	Press Condition								Evaluation index *			Amount of offset (mm)		Remarks
	Number of passes	θb (°)	θn (°)	Lb (mm)	Ln (mm)	αb	βb	W (mm)	Left side of formula(1)	Right side of formula(1)	Evaluation	Minimum	Maximum	
1		15.2	8.3	124	67					130	×	3.0	8.0	Comparative Example
2		15.1	10.5	123	85					147	×	2.0	8.0	Comparative Example
3		15.0	12.7	122	103					165	×	3.0	6.0	Comparative Example
4	9	14.9	14.9	121	121	0.50	0.50	360	180	182	○	0.0	1.0	Invention Example
5		14.8	17.1	120	139					200	○	0.0	2.0	Invention Example
6		14.6	19.3	119	157					217	○	1.0	2.0	Invention Example
7		14.5	21.5	118	175					235	○	0.0	1.0	Invention Example
8		15.2	8.3	124	67					130	×	4.0	9.0	Comparative Example
9		15.1	10.5	123	85					147	×	3.0	6.0	Comparative Example
10		15.0	12.7	122	103					165	×	1.0	8.0	Comparative Example
11	9	14.9	14.9	121	121	0.50	0.50	380	190	182	×	2.0	6.0	Comparative Example
12		14.8	17.1	120	139					200	○	1.0	2.0	Invention Example
13		14.6	19.3	119	157					217	○	1.0	2.0	Invention Example
14		14.5	21.5	118	175					235	○	0.0	1.0	Invention Example
15		26.1	22.0	213	180					286	×	3.0	8.0	Comparative Example
16		25.9	23.2	212	190					295	×	2.0	8.0	Comparative Example
17		25.8	24.5	211	200					305	×	3.0	6.0	Comparative Example
18	5	25.7	25.7	210	210	0.50	0.50	620	310	314	○	1.0	3.0	Invention Example
19		25.6	26.9	209	220					324	○	0.0	2.0	Invention Example
20		25.4	28.1	208	230					333	○	0.0	1.0	Invention Example
21		25.3	29.4	207	240					343	○	1.0	2.0	Invention Example
22		26.1	19.1	213	156					262	×	4.0	12.0	Comparative Example
23		25.9	21.3	212	174					279	×	5.0	7.0	Comparative Example
24		25.8	23.5	211	192					297	×	3.0	8.0	Comparative Example
25	5	25.7	25.7	210	210	0.50	0.50	640	320	314	×	8.0	10.0	Comparative Example
26		25.6	27.9	209	228					332	○	1.0	2.0	Invention Example
27		25.4	30.1	208	246					349	○	1.0	2.0	Invention Example
28		25.3	32.3	207	264					367	○	0.0	1.0	Invention Example

* Formula (1): $\beta_b \cdot W < \alpha_b \cdot L_b/2 + L_n$

Example 4

[0050] In the same manner as Examples 1 to 3, an open pipe for a welded steel pipe having various strengths and dimensions is manufactured. Table 4 illustrates strength grade and dimension of a product, a radius of a tool used as an end bending condition, a machining width (range of end bending), a bend angle, and the press conditions. In addition, the punch shift ratio and the die shift ratio are set to 0.5. In addition, the band angle per pass, the forming range, the punch shift ratio, and the die shift ratio of other passes of the second half press forming are the same as those of the final pass of the second half press forming, and the number of presses and the conditions of the first half press forming are the same as those of the second half press forming.

[0051] The amount of offset of the welded part of each open pipe is measured and evaluated in the same manner as Example 1, and the results thereof are indicated in Table 4.

[0052] From Table 4, it is understood that when performing the three-point bending press forming under the conditions of Formula (1) of the present invention, the amount of offset of the welded part of the open pipe is suppressed to the correctable range, irrespective of the variation in the forming range and the bend angle caused by strength and size of the steel pipe.

[Table 4]

№	Strength of Product and Dimension				End Bending Condition			Press Condition						Evaluation Index *			Amount of offset (mm)		Remarks
	API Grade	Outer Diameter (mm)	Pipe Thickness (mm)	Plate Width (mm)	Tool R (mm)	Machining width (mm)	Bend Angle (°)	Number of Passes	Punch R (mm)	θb (°)	Lb (mm)	Ln (mm)	W (mm)	Left Side of Formula(1)	Right side of formula(1)	Evaluation	Minimum	Maximum	
1	X80	508	25.4	1501	150	120	30.7	4	170	28.0	140	140	420	210	210	○	0.0	3.0	Invention Example
2	X80	508	25.4	1501	150	120	30.7	4	170	28.0	140	140	440	220	210	×	1.0	8.0	Comparative Example
3	X80	610	25.4	1817	210	140	24.5	4	200	29.1	155	155	460	230	233	○	1.0	3.0	Invention Example
4	X80	610	25.4	1817	210	140	24.5	4	200	29.1	155	155	480	240	233	×	4.0	9.0	Comparative Example
5	X80	762	31.8	2271	210	140	21.3	5	255	25.5	168	168	500	250	252	○	0.0	2.0	Invention Example
6	X80	762	31.8	2271	210	140	21.3	5	255	25.5	168	168	520	260	252	×	3.0	9.0	Comparative Example
7	X80	1067	31.8	3219	280	210	18.2	5	370	26.7	254	254	760	380	382	○	0.0	2.0	Invention Example
8	X80	1067	31.8	3219	280	210	18.2	5	370	26.7	254	254	780	390	382	×	2.0	10.0	Comparative Example
9	X80	1219	31.8	3693	280	210	18.2	5	425	27.5	298	298	880	440	446	○	0.0	1.0	Invention Example
10	X80	1219	31.8	3693	280	210	18.2	5	425	27.5	298	298	900	450	446	×	3.0	9.0	Comparative Example
11	X80	1422	31.8	4325	450	210	14.5	5	500	28.2	355	355	1060	530	533	○	1.0	2.0	Invention Example
12	X80	1422	31.8	4325	450	210	14.5	5	500	28.2	355	355	1080	540	533	×	2.0	12.0	Comparative Example
13	X56	914	31.8	2745	280	210	20.3	5	315	25.7	211	211	620	310	317	○	0.0	1.0	Invention Example
14	X56	914	31.8	2745	280	210	20.3	5	315	25.7	211	211	640	320	317	×	0.0	6.0	Comparative Example
15	X65	914	31.8	2745	280	210	20.0	5	315	25.7	211	211	620	310	317	○	0.0	2.0	Invention Example
16	X65	914	31.8	2745	280	210	20.0	5	315	25.7	211	211	640	320	317	×	2.0	7.0	Comparative Example
17	X100	914	31.8	2745	280	210	16.8	5	315	25.7	211	211	620	310	317	○	0.0	3.0	Invention Example
18	X100	914	31.8	2745	280	210	16.8	5	315	25.7	211	211	640	320	317	×	1.0	9.0	Comparative Example
19	X80	914	25.4	2765	280	210	19.5	5	315	25.8	213	213	620	310	320	○	0.0	2.0	Invention Example
20	X80	914	25.4	2765	280	210	19.5	5	315	25.8	213	213	640	320	320	×	3.0	8.0	Comparative Example
21	X80	914	38.1	2726	280	210	16.0	5	315	25.7	210	210	620	310	314	○	0.0	1.0	Invention Example
22	X80	914	38.1	2726	280	210	16.0	5	315	25.7	210	210	640	320	314	×	1.0	7.0	Comparative Example

* Formula (1): $\beta_b \cdot W < \alpha_b \cdot L_b/2 + L_n$

Claims

1. A method of manufacturing a welded steel pipe, the method comprising:

performing three-point bending press forming on a raw material steel plate by a pair of dies disposed in a steel plate feeding direction at a predetermined gap, and a punch configured to press the steel plate between the pair of dies to form an open pipe; and
welding the open pipe,
wherein, when the open pipe is formed such that after performing first half press forming from one width end portion of the steel plate toward a width center (provided, leaving the width center unpressed), second half press forming is performed from a width end portion of an opposite side toward the width center (provided, leaving the width center unpressed), and the width center is finally subjected to final press forming, the steel pipe, supported on the dies of the steel plate width center side, is assumed to be a non-formed portion in a final pass of the second half press forming.

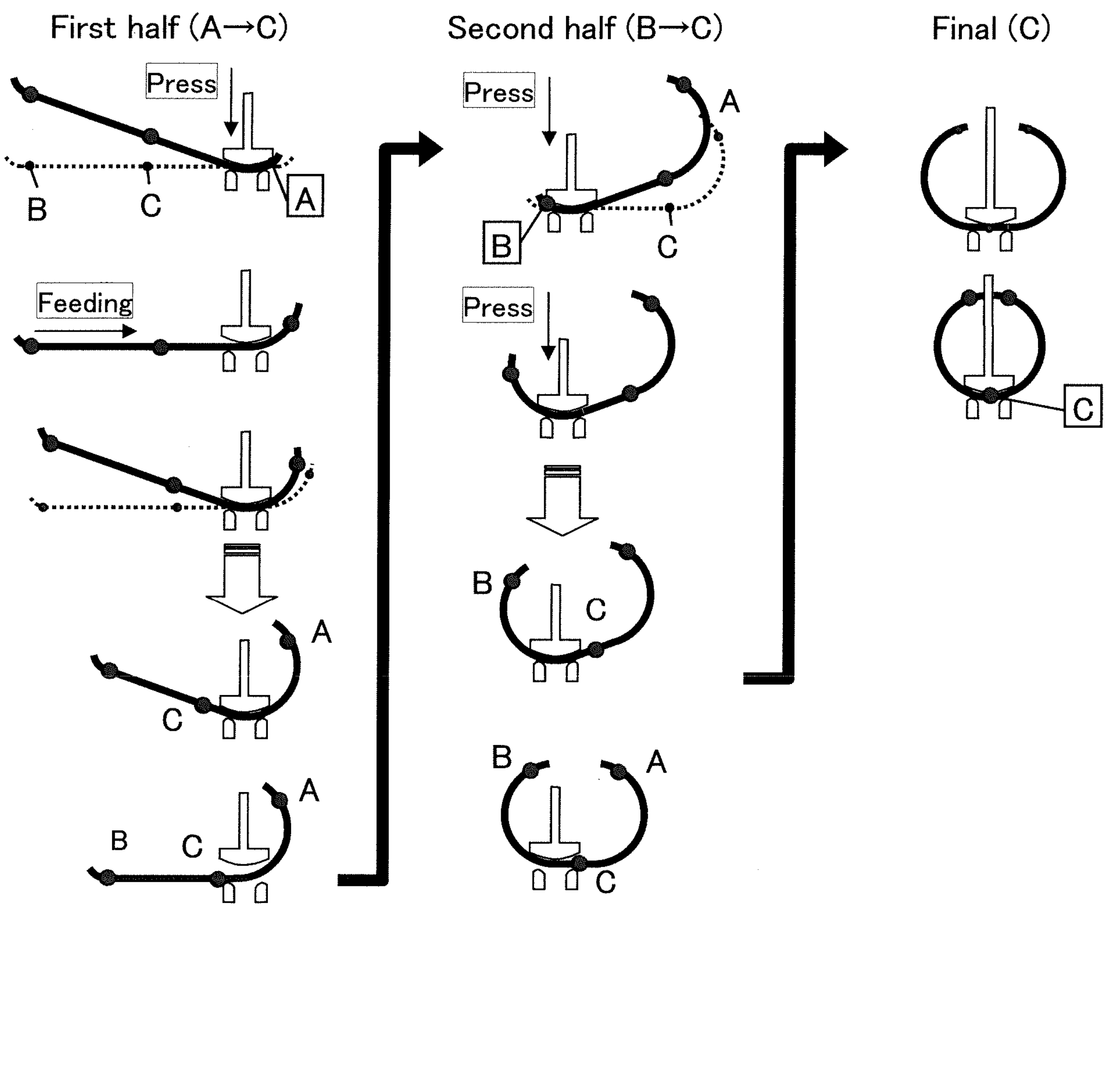
2. The method of manufacturing a welded steel pipe according to claim 1, wherein the final pass of the second half press forming satisfies the following Formula (1):

$$\beta_b \cdot W < \alpha_b \cdot L_b + L_n \ldots (1)$$

where, L_b represents forming range (mm) in the final pass of the second half press forming,
L_n represents forming range (mm) in the final press forming,
W represents die gap (mm),
α_b represents shift ratio (-) of steel plate position in the final pass of the second half press forming, and

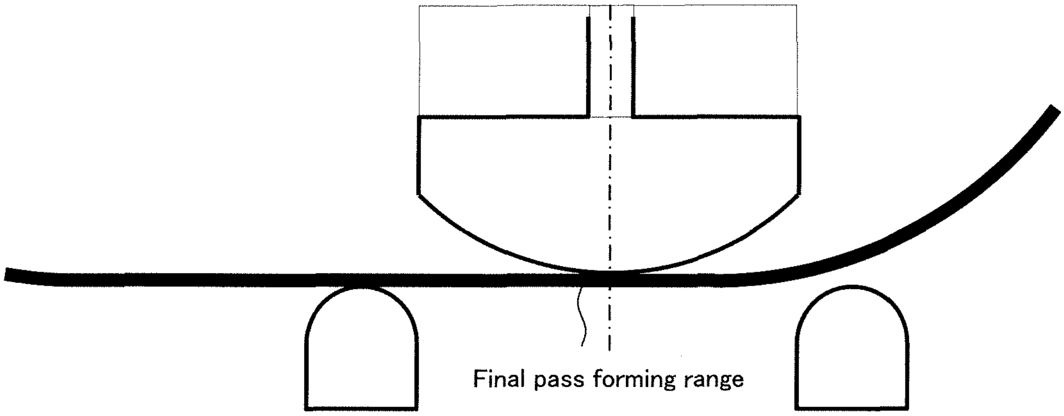
β_b represents shift ratio (-) of die position in the final pass of the second half press forming.

【Fig. 1】

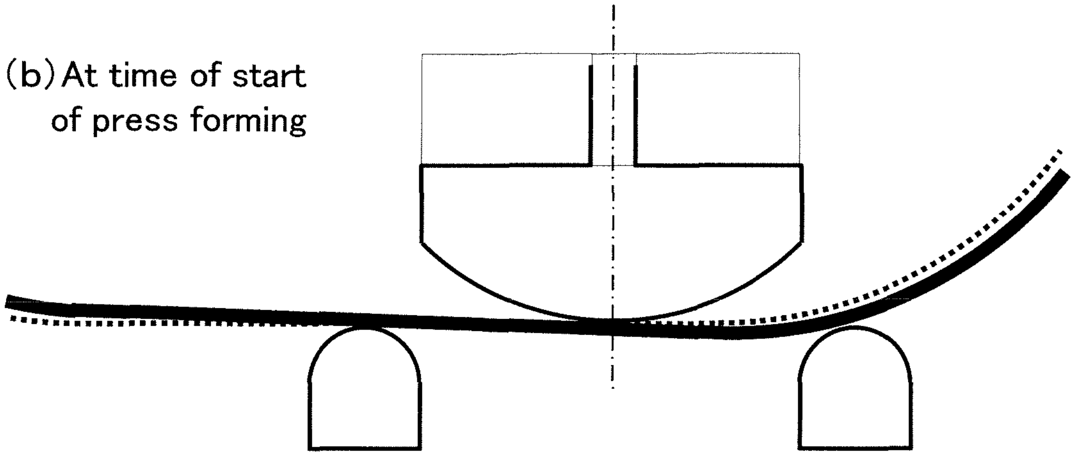

First half (A→C)
Second half (B→C)
Final (C)
Press
A
B
C
Feeding
A
C
B
C
A
Press
A
B
C
Press
B
C
B
A
C
C

【Fig. 2】

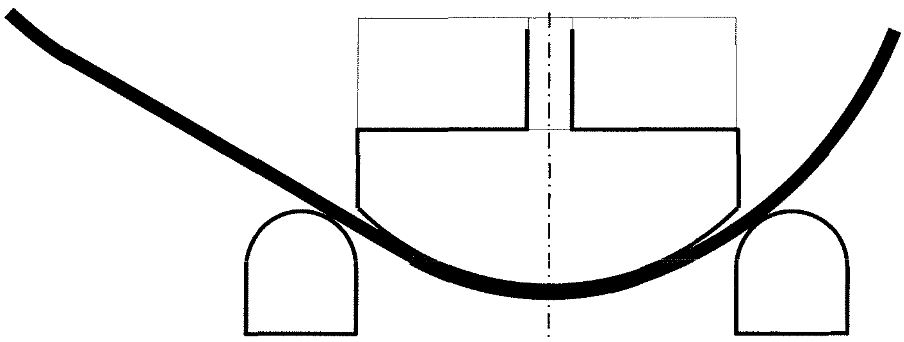
(a) When steel plate feeding is completed



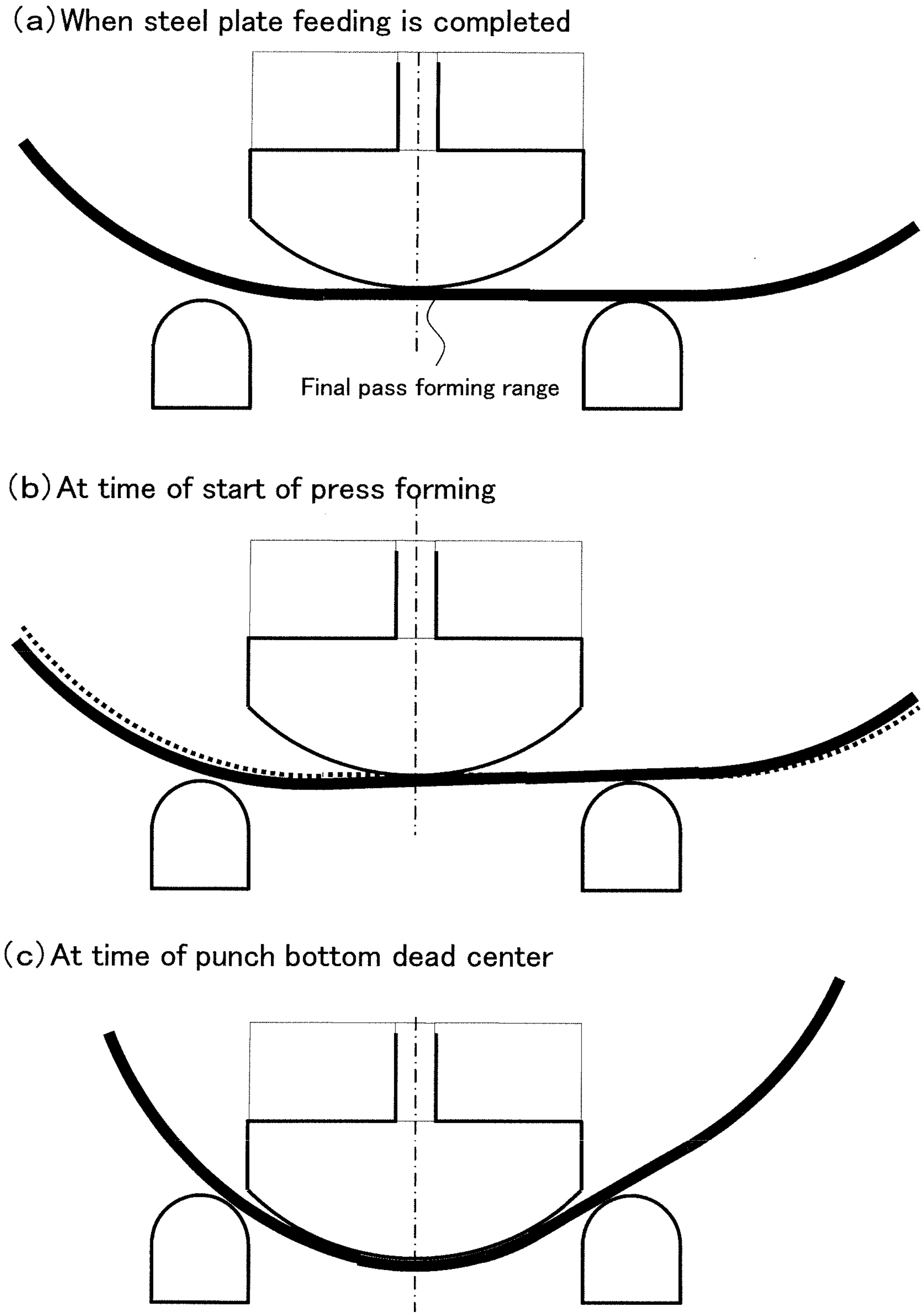
(b) At time of start of press forming



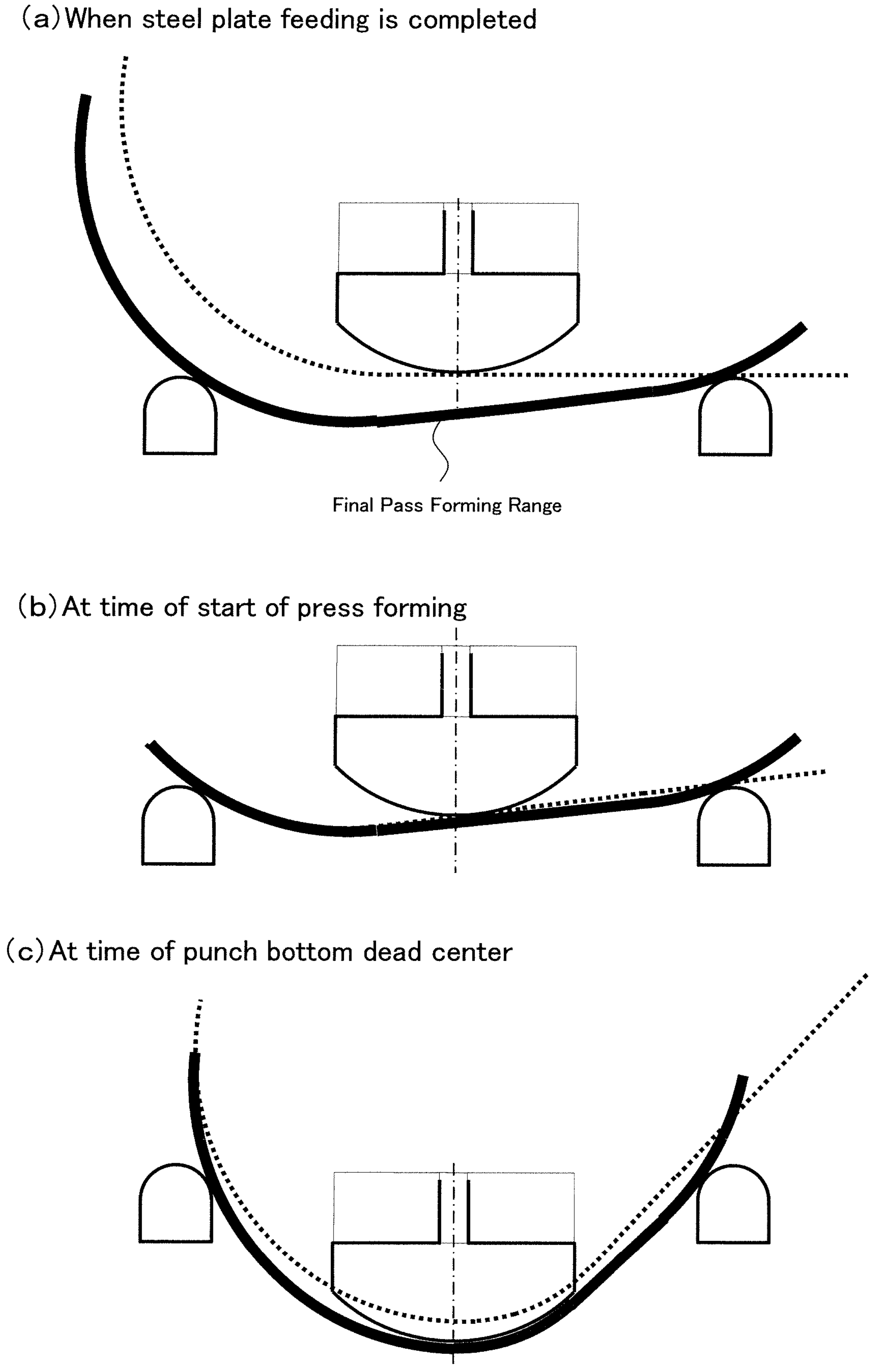
(c) At time of punch bottom dead center



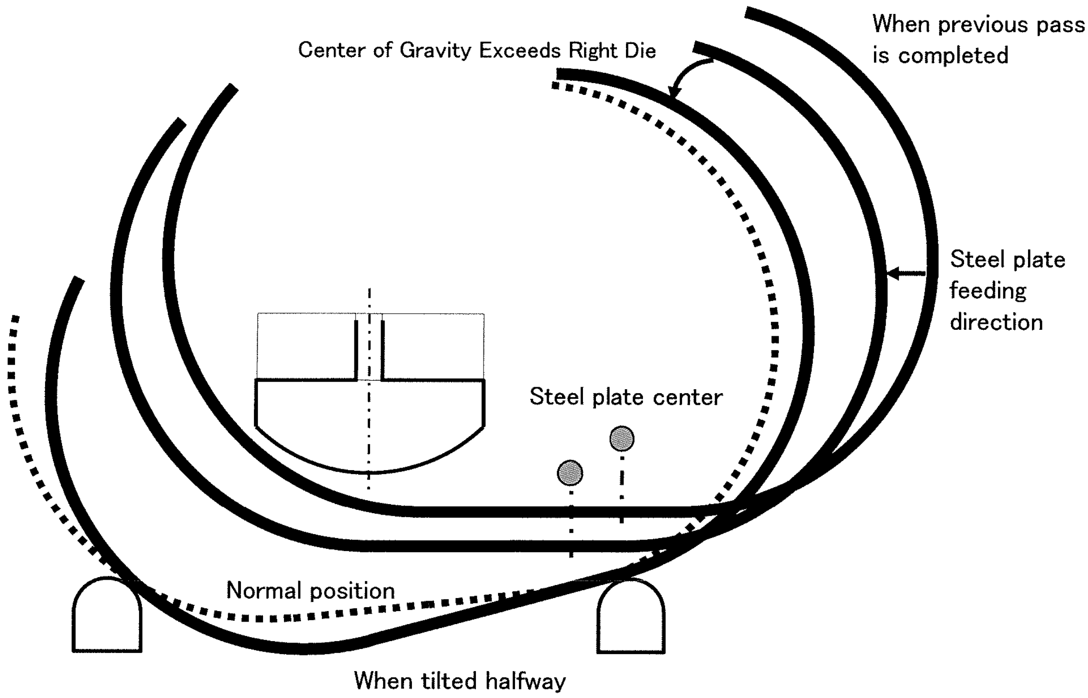
【Fig. 3】


(a) When steel plate feeding is completed
Final pass forming range
(b) At time of start of press forming
(c) At time of punch bottom dead center

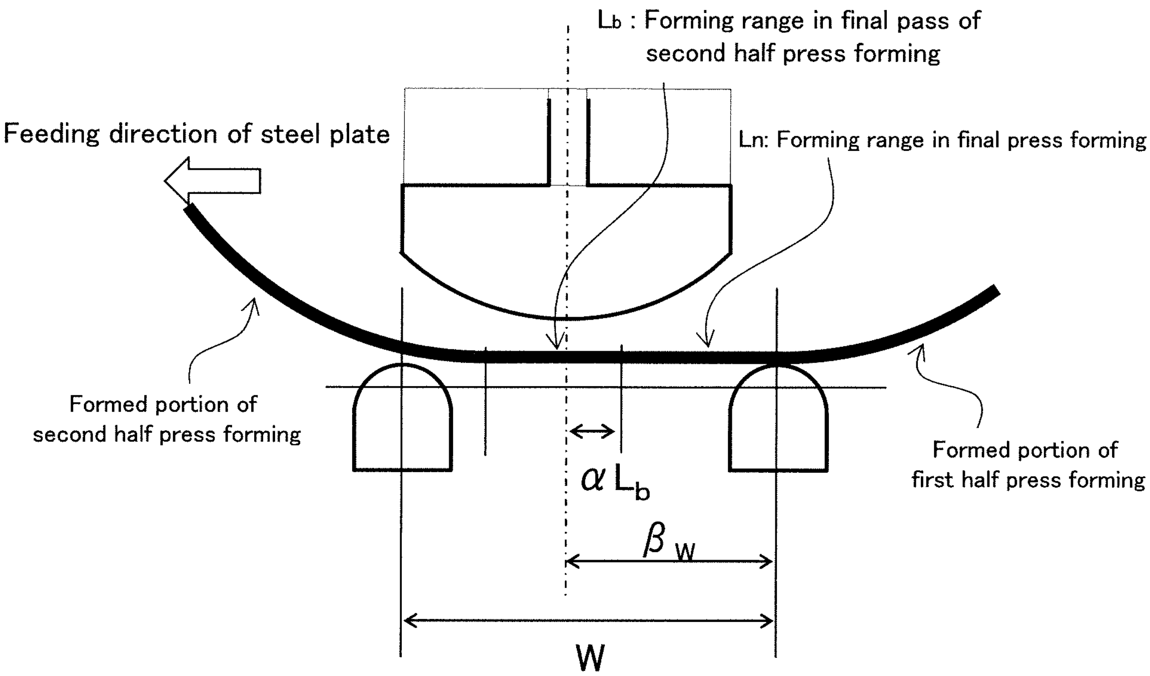
【Fig.4】


(a) When steel plate feeding is completed
Final Pass Forming Range
(b) At time of start of press forming
(c) At time of punch bottom dead center

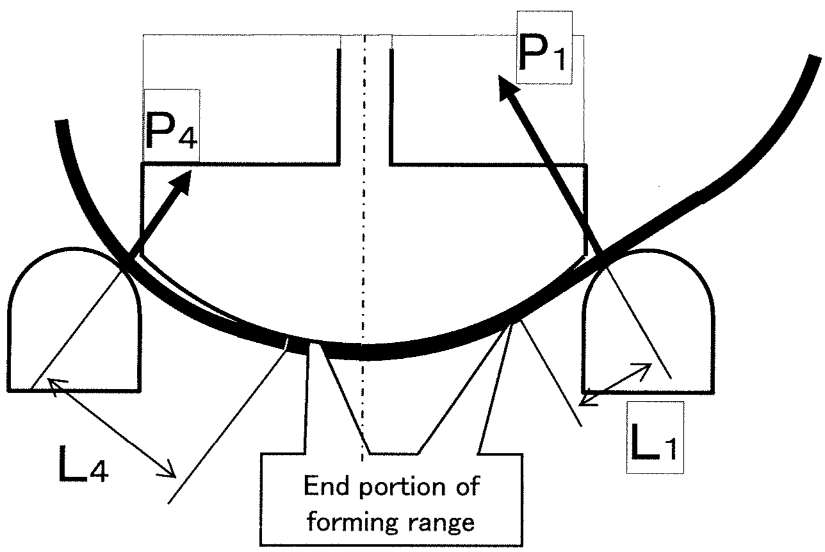
【Fig. 5】


When previous pass
is completed
Center of Gravity Exceeds Right Die
Steel plate
feeding
direction
Steel plate center
Normal position
When tilted halfway

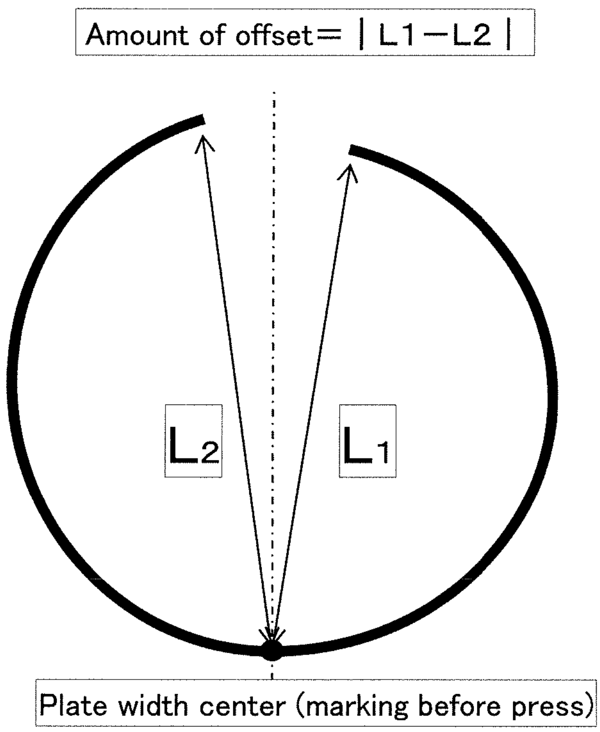
【Fig.6】


Lb : Forming range in final pass of second half press forming
Feeding direction of steel plate
Ln: Forming range in final press forming
Formed portion of second half press forming
Formed portion of first half press forming
α Lb
β W
W

【Fig.7】



【Fig.8】


Amount of offset= | L1−L2 |
L2
L1
Plate width center (marking before press)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/064852

A. CLASSIFICATION OF SUBJECT MATTER
B21D5/01(2006.01)i, *B21C37/08*(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)
B21D5/01, B21C37/08

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	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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.
Y	JP 2012-170977 A (JFE Steel Corp.), 10 September 2012 (10.09.2012), paragraphs [0004], [0012] to [0013]; fig. 3 to 4 (Family: none)	1-2
Y	JP 11-129031 A (Mitsubishi Heavy Industries, Ltd.), 18 May 1999 (18.05.1999), paragraphs [0025] to [0026] (Family: none)	1-2
A	JP 2012-250285 A (SMS Meer GmbH), 20 December 2012 (20.12.2012), entire text; all drawings & EP 2529849 A2 & CN 102806245 A	1-2

☒ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
20 August, 2013 (20.08.13)	03 September, 2013 (03.09.13)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/064852

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 2004-82219 A (SMS Meer GmbH), 18 March 2004 (18.03.2004), entire text; all drawings & US 2004/0055356 A1 & EP 1382402 A2 & DE 10232098 A1	1-2
A	JP 10-166059 A (Mitsubishi Heavy Industries, Ltd.), 23 June 1998 (23.06.1998), entire text; all drawings (Family: none)	1-2

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Patent documents cited in the description

- JP 11129031 A **[0007]**
- JP 2007090406 A **[0007]**
- JP 2005324255 A **[0007]**