## DESCRIPTION

# ULTRASONIC FLAW INSPECTION METHOD FOR CAST BAR AND ULTRASONIC FLAW INSPECTION DEVICE

## TECHNICAL FIELD

[0001] The present invention relates to an ultrasonic flaw inspection method for a cast bar with a circular cross-section and an ultrasonic flaw inspection device for performing the inspection method.

## BACKGROUND ART

[0002] Generally, a continuous cast bar is manufactured by casting molten metal into a columnar, rectangular columnar, or hollow columnar long ingot. Such casting methods include a float casting method, a direct chill casting (DC casting) method, a gas-pressure-applied Hot-top continuous casting method. For a continuous cast bar, elimination of the surface uneven layer which may cause breaking during plastic working is performed, and inspection is conducted for surface defects and internal defects after elimination of the outer peripheral portion (See Patent Document 1).

[0003] In the manufacturing process for the continuous cast bar as disclosed in Patent Document 1, a non-disruptive inspection process for internal defects by ultrasonic flaw inspection is performed between the continuous casting process and the outer

periphery elimination process. The ultrasonic flaw inspection is characterized in that the inspection is high in detection capability for interior defects such as breakage and that the inspection enables easy automatic judgment of defects by processing detected electric signals as compared to an X-ray inspection that requires image processing, which in turn enables stable inspection with a high degree of accuracy.

[0004] When inspecting for defects of a cast bar in the vicinity of the surface thereof using a longitudinal vertical wave as an incident wave, a bottom reflection echoes are detected as false defect echoes. Therefore, an inclined angle wave is conventionally used as the incident wave.

[Patent Document 1]

Japanese Unexamined Laid-open Patent Application Publication No. 2004-209516

## SUMMARY OF THE INVENTION

### PROBLEMS TO BE SOLVED BY THE INVENTION

[0005] However, when obtaining an inclined angle wave using a conventional ultrasonic flaw inspection probe, the obtained wave becomes a transverse wave. In the case of performing inspection of a surface or the vicinity thereof using a transverse wave slower in sound speed than a longitudinal wave, there was a drawback that false defect echoes were more likely detected due to the long temporal axes.

[0006] Furthermore, in the case of inspecting an entire region

of a cast bar circular in cross-section using a conventional probe, it was required to move the probe in the circumferential direction of the continuous cast bar, or arrange a number of ultrasonic flaw inspection probes in the circumferential direction. Furthermore, it was difficult to arrange a number of probes with a high degree of precision, and the low-precision arrangement of the probes caused a deterioration of the inspection accuracy.

## MEANS FOR SOLVING THE PROBLEMS

[0007] In view of the aforementioned technical background, the present invention aims to provide an ultrasonic flaw inspection method for a cast bar circular in cross-section capable of inspecting an entire region of the cast bar using a longitudinal wave as an incident wave, and also to provide an ultrasonic flaw inspection device for performing the inspection method.

[0008] That is, the present invention has a structure as recited in the following items [1] to [9].

[0009] [1] An ultrasonic flaw inspection method for a cast bar,

wherein, in performing ultrasonic flow inspection by arranging a plurality of phased array type probes in a circumferential direction of the cast bar circular in cross-section at a predetermined angle,

one of the phased array type probes and the other phased array type probe are arranged such that an uninspected region by a longitudinal inclined angle wave and a longitudinal vertical

wave of the one of the phased array type probes is complemented with an inspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the other phased array type probe.

[0010] [2] The ultrasonic flaw inspection method as recited in the aforementioned item 1, wherein the two phased array type probes are arranged at an arrangement angle $\alpha$ which satisfies following two formulas:

$$2 \times (180° - 2\theta_2 + \theta_3) \leqq \alpha \leqq 2\theta_2 - \theta_3 - \theta_4$$

$$180° - [3\theta_3 + 3(180° - 2\theta_2)] \geqq \theta_4$$

where

$\theta_2$: effective inclined angle of a phased array type probe

$\theta_3$: central angle of OP

$\theta_4$: 1/2 of a central angle of a dead zone of a vertical incident wave of the phased array type probe

O: incident point of the vertical incident wave of the phased array type probe

P: incident point of an inclined angle incident wave at the maximum scanning angle of the phased array type probe.

[0011] [3] The ultrasonic flaw inspection method for a cast bar as recited in the aforementioned item 2, wherein the two phased array type probes are arranged so that the incident waves travel downward.

[0012] [4] The ultrasonic flaw inspection method for a cast bar as recited in any one of the aforementioned items 1 to 3, wherein

a plurality of phased array type probes are arranged at a vicinity of a casting mold outlet of a horizontal continuous casting mold and ultrasonic flaw inspection is continuously performed for a continuous cast bar which is being continuously cast.

[0013] [5] The ultrasonic flaw inspection method as recited in the aforementioned item 4, wherein the continuous cast bar is loosely inserted into a through-hole of a dam-like member arranged apart from the casting mold outlet at a downstream side to interrupt flow of the cooling water, and

wherein the phased array type probes are arranged in a state in which the probes are in contact with the cooling water that the flow is interrupted.

[0014] [6] An ultrasonic flaw inspection device for a cast bar, comprising a plurality of phased array type probes arranged in a circumferential direction of the cast bar circular in cross-section, and

one of the phased array type probes and the other phased array type probe are arranged such that an uninspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the one of the phased array type probes is complemented with an inspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the other phased array type probe.

[0015] [7] The ultrasonic flaw inspection device for a cast bar as recited in the aforementioned item 6, wherein the two phased array type probes are arranged at an arrangement angle $\alpha$ which

satisfies following two formulas:

$$2 \times (180° - 2\theta_2 + \theta_3) \leqq \alpha \leqq 2\theta_2 - \theta_3 - \theta_4$$

$$180° - [3\theta_3 + 3(180° - 2\theta_2)] \geqq \theta_4$$

where

$\theta_2$: effective inclined angle of a phased array type probe

$\theta_3$: central angle of OP

$\theta_4$: 1/2 of a central angle of a dead zone of a vertical incident wave of the phased array type probe

O: incident point of the vertical incident wave of the phased array type probe

P: incident point of an inclined angle incident wave at the maximum scanning angle of the phased array type probe.

[0016] [8] A consistent manufacturing method for a forged product,

wherein, in a consistent production method of a cast product in which a continuous cast bar circular in cross-section which is being continuously cast from a casting mold outlet of a horizontal continuous casting device is subjected to short-length cutting, peeling, and heat-treatment in an arbitrary order, and subsequently subjected to forging, ultrasonic flaw inspection is performed immediately after casting or between arbitrary processes, and

wherein the ultrasonic flaw inspection is performed by arranging a plurality of phased array type probes in a circumferential direction of the cast bar circular in cross-section at a predetermined angle, and arranging one of the phased array type probes and the other phased array type probe such that an

uninspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the one of the phased array type probes is complemented with an inspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the other phased array type probe.

[0017] [9] The consistent manufacturing method for a forged product as recited in the aforementioned item 8, wherein the ultrasonic flaw inspection is performed by arranging two phased array type probes at an arrangement angle $\alpha$ which satisfies following two formulas:

$$2 \times (180° - 2\theta_2 + \theta_3) \leqq \alpha \leqq 2\theta_2 - \theta_3 - \theta_4$$

$$180° - [3\theta_3 + 3(180° - 2\theta_2)] \geqq \theta_4$$

where

$\theta_2$: effective inclined angle of a phased array type probe

$\theta_3$: central angle of OP

$\theta_4$: 1/2 of a central angle of a dead zone of a vertical incident wave of the phased array type probe

O: incident point of the vertical incident wave of the phased array type probe

P: incident point of an inclined angle incident wave at the maximum scanning angle of the phased array type probe.

## EFFECTS OF THE INVENTION

[0018] According to the ultrasonic flaw inspection method as recited in the aforementioned Item [1], a longitudinal inclined

angle wave and a longitudinal vertical wave are injected to the cast bar circular in cross-section using phased array type probes to perform ultrasonic flaw inspection of the entire region of the cast bar including the vicinity of the surface. Also, with a longitudinal wave high in sound velocity, false defect echoes are not likely to appear on a flaw inspection display and flaw inspection of a wide region can be performed with a single probe, which enables to attain high inspection accuracy.

[0019] According to the ultrasonic flaw inspection method as recited in the aforementioned Item [2], an arrangement angle $\alpha$ of probes which can complement uninspected regions of each of the two phased array type probes can be derived.

[0020] According to the ultrasonic flaw inspection method as recited in the aforementioned Item [3], the ultrasonic wave which propagated through water is sufficiently attenuated before reaching the surface of the water, and therefore occurrence of false defect signals can be reduced, enabling highly accurate flaw inspection.

[0021] According to the ultrasonic flaw inspection method as recited in the aforementioned Item [4], the inspection efficient is excellent since horizontal continuous casting and ultrasonic flaw inspection can be continuously performed, and the inspection result can be reflected in the following processes, or can be fed back for casting conditions. In addition, since there are no end surfaces in the inspection target regions, there are no dead zones in end surfaces. Therefore, cut pieces cut after the inspection can be treated as pieces inspected up to the end surfaces.

[0022] According to the ultrasonic flaw inspection as recited in the aforementioned Item [5], continuous ultrasonic flaw inspection can be performed with a simple device subsequent to horizontal continuous casting.

[0023] According to the ultrasonic flaw inspection device as recited in the aforementioned Items [6] and [7], the aforementioned ultrasonic flaw inspection can be performed.

[0024] According to the consistent manufacturing method of a forged product as recited in the aforementioned Items [8] and [9], since the aforementioned ultrasonic flaw inspection is conducted between processes, high quality forged products can be manufactured with high efficiency.

## BRIEF DESCRIPTION OF DRAWINGS

[0025] [Fig. 1] Fig. 1 is a explanatory view showing uninspected regions of phased array type probes in an ultrasonic flaw inspection of a cast article with a circular cross-section.

[Fig. 2] Fig. 2 is a view showing propagation of an ultrasonic wave in ultrasonic flaw inspection of a cast article according to the present invention and an arrangement angle of two phased array type probes.

[Fig. 3] Fig. 3 is an enlarged view of an essential portion shown in Fig. 2.

[Fig. 4A] Fig. 4A is a schematic front view showing an embodiment of an ultrasonic flaw inspection device according to the present invention.

[Fig. 4B] Fig. 4B is a side view of the ultrasonic flaw inspection device shown in Fig. 4A.

[Fig. 5] Fig. 5 is a perspective view including a partial cross-section schematically showing another embodiment of the ultrasonic flaw inspection device according to the present invention.

[Fig. 6A] Fig. 6A is a process flowchart of a consistent manufacturing method of a forged product from casting to forging, wherein an inspection process using an ultrasonic flaw inspection device according to the present invention is employed.

[Fig. 6B] Fig. 6B is a process flowchart of a consistent manufacturing method of a forged product from casting to forging, wherein an inspection process using an ultrasonic flaw inspection device according to the present invention is employed.

[Fig. 6C] Fig. 6C is a process flowchart of a consistent manufacturing method of a forged product from casting to forging, wherein an inspection process using an ultrasonic flaw inspection device according to the present invention is employed.

## BRIEF DESCRIPTION OF THE REFERENCE NUMERALS

[0026] 1: phased array type probe

1A, 2A: out-of-scanning region (uninspected region)

1B, 2B: dead zone (uninspected region)

10, 40: ultrasonic flaw inspection device

33: casting mold

35: cooling water

41: through-hole

42: dam-like member

S: cast bar (continuous cast bar)

## BEST MODE FOR CARRYING OUT THE INVENTION

[0027] A phased array type probe used in the present invention has a plurality of probes arranged in parallel with each other (probe block), and is electrically controllable in focal point, which enables multi-focusing (combination of vertical flaw inspection and inclined angle flaw inspection) during the inspection and wide region inspection. In the case of a longitudinal wave having a faster sound speed than a transverse wave, false defect echoes are less likely to appear on a flaw inspection display, and therefore the inspection accuracy is high. A single probe block can conduct a wide range flaw inspection and therefore deterioration of inspection accuracy due to deterioration of positional accuracy cased by arranging a number of probes in a circumferential direction in a conventional inspection method will not occur, resulting in high inspection accuracy.

[0028] The aforementioned phased array type probe can perform a wide range of inspection for flaws with a longitudinal inclined angle (including vertical) wave, but uninspected regions still remain inevitably. In the present invention, a plurality of phased array type probes are arranged around a cast bar circular in cross-section in a circumferential direction thereof at predetermined angles so as to complement each other' s uninspected

region, which enables inspection covering an entire region of the cast bar including the vicinity of the surface.

[0029] Fig. 1 shows an example in which two phased array type probes 1 and 2 are arranged with respect to a cast bar S circular in cross-section.

[0030] With respect to the first phased array type probe 1, "1A" and "1A" denote out-of-scanning regions deviated from a maximum scanning range, and "1B" denotes a dead zone which occurs since the bottom echo that appears when an incident light is injected in a vertical direction cannot be distinguished from a defect echo. These regions 1A, 1A and 1B are uninspected regions that the first phased array type probe 1 cannot inspect for flaws. The out-of-scanning regions 1A and 1A can be reduced by enlarging the scanning region, but such regions cannot be completely eliminated because the scanning target is circular in cross-section. Also, the aforementioned dead zone 1B is a region which is inevitably created. Similarly, with respect to the second phased array type probe 2, "2A" and "2A" denote out-of-scanning regions deviated from a maximum scanning range, and "2B" is a dead zone due to a false defect echo, or an uninspected region that cannot be inspected for flaws by the second phased array type probe 2.

[0031] As understood from Fig. 1, by arranging the first phased array type probe 1 and the second phased array type probe 2 so as to avoid overlapping of their uninspected regions, an entire region can be inspected. Specifically, if the margin C between the out-of-scanning region 1A of the first phased array type probe

1 and the out-of-scanning region 2A of the second phased array type probe 2, and a margin D between the out-of-scanning region 2A of the second phased array type probe 2 and the dead zone 1B of the first phased array type probe 1 are secured, the entire region can be inspected.

[0032] Hereinafter, in accordance with the aforementioned way of thinking, a method of obtaining conditions that, when the margin C is equal to 0 (margin C=0), the margin D becomes equal to 0 or more (margin D ≥0), or uninspected regions of the two phased array type probes 1 and 2 do not overlap, will be explained with reference to the ultrasonic wave propagation path diagram shown in Fig. 2.

[0033] Fig. 2 shows a state in which the margin C is equal to 0 (margin C=0), and the out-of-scanning region 1A of the first phased array type probe 1 and the out-of-scanning region 2A of the second phased array type probe 2 are in contact with each other in an non-overlapped state. The two phased array type probes 1 and 2 have the same functions, and will be explained using the same reference symbol.

[0034] The symbols in Fig. 2 denote as follows. In Fig. 2, only the left half propagation path in the cast bar S is shown, and the right half propagation path is not illustrated.

[0035] $\alpha$: arrangement angle of the two phased array type probes

$\theta_1$: maximum scanning angle of the phased array type probe

$\theta_2$: effective inclined angle of the phased array type probe

$\theta_3$: central angle of the OP

$\theta_4$: 1/2 of the central angle of the dead zone by a vertical

incident wave of the phased array type probe

$\theta_5$: central angle of the margin D

O: incident point of the vertical incident wave of phased array type probe

P: incident point of the inclined angle incident wave of phased array type probe at the time of the maximum scanning angle

Q: vertical line

r: radius of the cast bar

From Fig. 2, when the margin C is equal to 0 (margin C=0), the arrangement angle $\alpha$ of the two phased array type probes 1 and 2 is expressed by the following formula (i), and the central angle $\theta_4$ of the dead zone 1B in which the dead zone 1B of the first phased array type probe 1 and the out-of-scanning region 2A of the second phased array type probe 2 do not overlap must satisfy the following formula (ii).

[0036] $$\alpha = 2 \times (180° - 2\theta_2 + \theta 3) \quad \ldots(i)$$

$$180° - [3\theta_3 + 3\ (180° - 2\theta_2)] \geqq \theta_4 \quad \ldots(ii)$$

The aforementioned formula (i) expresses the minimum value ($\alpha_{min}$) of the arrangement angle $\alpha$ of the two phased array type probes 1 and 2, and therefore,

$$\alpha_{min} = 2 \times (180° - 2\theta_2 + \theta_3) \quad \ldots(iii)$$

From the formula (ii), the central angle $\theta_5$ of the margin D is expressed by the following formula (iv).

[0037] $$\theta_5 = 180° - [3\theta_3 + 3\ (180° - 2\theta_2)] - \theta_4 \quad \ldots(iv)$$

The aforementioned arrangement angle $\alpha$ can be enlarged until the margin D becomes 0 (margin D= 0), and therefore the maximum value $\alpha_{max}$ of the arrangement angle $\alpha$ is expressed by the following formula (v).

[0038] $$\alpha_{max} = \alpha_{min} + \theta_5$$
$$= 2\theta_2 - \theta_3 - \theta_4 \quad \ldots(v)$$

Consequently, the range of the arrangement angle $\alpha$ for inspecting the entire region of the cast bar S can be defined by a range that satisfies the aforementioned formula (ii) and falls within the range covering from the minimum value $\alpha_{min}$ expressed by the formula (iii) to the maximum value $\alpha_{max}$ expressed by the formula (v). That is, by arranging the two phased array type probes 1 and 2 so as to satisfy the following two formulas, the entire region of the cast bar S circular in cross-section can be inspected.

[0039] $$180° - [3\theta_3 + 3\ (180° - 2\theta_2)] \geqq \theta_4$$
$$2 \times (180° - 2\theta_2 + \theta_3) \leqq \alpha \leqq 2\theta_2 - \theta_3 - \theta_4$$

Next, the numerical values to be substituted into each of the aforementioned formulas will be explained.

[0040] The maximum scanning angle $\theta_1$ is an angle to be determined according to the specifications of the phased array type probe.

[0041] The effective inclined angle $\theta_2$ is an angle that is determined by the angle of refraction and the aforementioned maximum scanning angle $\theta_1$, preferably considering the degree of attenuation of the ultrasonic wave and the defect size to be detected.

[0042] The central angle $\theta_3$ of OP, as shown in Fig. 3, can be expressed by the following formula (vi) with the distance $x_1$ between the OP and the radius r of the cast bar S.

[0043] $$\theta_3 = \mathrm{Sin}^{-1}(x_1/r) \quad \ldots(vi)$$

However, if a measurement of the distance $x_1$ between OP is difficult, then because the relationship of $x_1$ and the size $x_2$ of the phased array type probe can be expressed by $x_1 \fallingdotseq x_2$, the central angle $\theta_3$ can be derived from the following formula (vi' ) using the measured $x_2$.

[0044] $$\theta_3 = \mathrm{Sin}^{-1}(x_2/r) \quad \ldots(vi')$$

The 1/2 of the central angle of the OP (i.e., $\theta_4$) expresses the size of the aforementioned dead zone 1B, and can be derived by the actual measurement.

[0045] Therefore, from the actually measured value, formula (iii), formula (iv), and formula (vi' ), the arrangement angle $\alpha$ of the two phased array type probes 1 and 2 that can inspect the entire region can be determined.

[0046] The aforementioned formula for calculating the arrangement angle $\alpha$ is based on two phased array type probes having the same specifications. However, when using phased array type probes different in specification, the arrangement angle can be derived based on the injection position of each probe and/or various angles. Furthermore, when using three or more phased array type probes, they should be arranged in a way such that the out-of-scanning regions of the adjacent probes do not overlap and the dead zone of one probe do not overlap with the out-of-scanning regions of

other probes.

[Example of the arrangement angle of two phased array type probes]

For ultrasonic flaw inspection for a cast bar S having a radius r of 215 mm, when the effective inclined angle $\theta_2$ of the phased array type probes 1 and 2 was 40° ($\theta_2$=40°), the size $x_2$ of the phased array type probes 1 and 2 was 28.7 mm ($x_2$=28.7 mm), and the size $\theta_4$ of the dead zone was 17.5° ($\theta_4$=17.5°), $\theta_3$=7.6° was derived from the formula (vi').

[0047] Therefore, from the formulas (iii) and (v), $\alpha_{min}$= 95.2°, and $\alpha_{max}$ = 114.9° was derived. Consequently, by arranging the two phased array type probes 1 and 2 within a range of the arrangement angles $\alpha$: 95.2 to 114.9°, the entire region can be inspected. However, considering wobbles caused by the traveling of the cast bar S during the inspection, it is preferable to arrange the probes at the intermediate point of the aforementioned range or the vicinity thereof by avoiding the arrangement at $\alpha_{min}$ and $\alpha_{max}$.

[0048] Also, the plurality of phased array type probes can be arranged at angles that complement the uninspected regions with each other, and therefore the phased array type probes can be arranged anywhere in the circumferential direction of the cast bar. However, as shown in the ultrasonic flaw inspection device 10 and 40, it is preferable that the phased array type probes 1 and 2 are arranged obliquely upward of the cast bar S to inject ultrasonic waves from upward to downward. If ultrasonic waves are irradiated from downward to upward, the ultrasonic wave that did not enter the cast bar S will be reflected by the surface of the water and its

echo can be detected as a false defect signal. However, by injecting ultrasonic waves from upward to downward, the ultrasonic waves that propagate the surface of the water sufficiently attenuate before reaching the surface of the water, and therefore its echo will not be detected as a false defect signal, enabling highly accurate flaw inspection. Also, when employing a copying mechanism for retaining the positional relationship of the phased array type probes 1 and 2 even if the cast bar S is displaced, there are less arrangement limitations when the probes are arranged above the cast bar S. For this reason, it is preferable to arrange them above the cast bar S.

[0049] Furthermore, it is preferable to set a sufficient distance (WD) between the cast bar S and the phased array type probes 1 and 2 so that repetitive echoes of the surface wave do not become false defect echoes.

[0050] Furthermore, a reflection echo from a wall surface of the inspection tank can become a false defect signal, and therefore it is preferable that the tank is large enough to prevent a false defect signal. It is preferable that the distance from the peripheral surface of the cast bar S to the wall surface of the tank is sufficiently enough to attenuate the ultrasonic wave that propagates through the water. Also, sound absorbent material can be arranged on the wall surface of the tank to eliminate the sound waves that become the cause of false defect echoes.

[0051] It should be understood that Figs. 1 to 3 show, for the convenience of explaining, that the first phased array type

probe 1 is arranged directly above, but do not show the most suitable positions of the phased array type probes 1 and 2 for the cast bar S. In the ultrasonic flaw inspection device 10 and 40, the phased array type probes 1 and 2 are arranged in such a way that the vertical line Q shown in Figs. 2 and 3 is arranged vertically.

**[ULTRASONIC FLAW INSPECTION DEVICE]**

**(FIRST EMBODIMENT)**

The ultrasonic flaw inspection device 10 shown in Figs. 4A and 4B is equipped with a water tank 11 and two phased array type probes 1 and 2, and configured to perform inspection of a cast bar S while moving the cast bar S.

[0052] The water tank 11 has walls arranged orthogonal to the travelling direction of the cast bar S, and the walls are provided with through-holes 12 and 13 to allow passage of the cast bar S. Water which is a contact medium is stored in the water tank 11 at a water level sufficiently higher than the through-holes 12 and 13. The two phased array type probes 1 and 2 are attached to both ends of a horizontal arm 16 provided at a tip end of a vertical arm 15 of a suspension system via brackets 17 in an angle adjustable manner so that ultrasonic waves are irradiated against the cast bar S travelling below the probes from diagonally upward portions of the probes. A copying roller 18 configured to come into contact with the cast bar S is attached to the middle portion of the horizontal arm 16 in the right-and-left direction to control movements of the arms 15 and 16 corresponding to positional displacements of

the cast bar S to always keep a certain positional relationship of the cast bar S and the phased array type probes 1 and 2.

[0053] The ultrasonic flaw inspection device 10 can inspect the travelling cast bar S regardless of the length of the cast bar S. For example, continuous inspection can be performed for a continuous cast bar S which is being continuously cast from the casting mold of a horizontal continuous casting device at a casting speed. Also, a cut cast bar can be inspected by moving the cast bar S at a predetermined speed using a moving device. In this way, by moving the cast bar S inside the tank 11, an inspection target can be subjected to inspection regardless of the length. Needless to say, in cases where an inspection target is smaller than the tank, the phased array type probes can be moved with the inspection target fixed.

[0054] The phased array type probes 1 and 2 are controlled by a control device (not shown) to detects flaws of the cast bar S. The signal emitted from the phased array type probes 1 and 2 are outputted to a signal processor 20, and then outputted to an ultrasonic flaw inspection device 21 after predetermined processing. The ultrasonic inspection judgment device 21 determines whether or not defects or flaws are present based on the inputted signals, and decides whether or not the cast bar S is a non-defective product. Further, in the case of continuous inspection of a continuous cast bar S continuously cast from a casting mold of a horizontal casting device, efficient inspection can be performed. In addition, a judgment result can be fed back to the casting conditions, or

defective portions can be marked with spray or the like and removed after cutting the cast bar into predetermined lengths with a cutting device (not illustrated) arranged at a downstream side. Alternatively, it can be configured such that detected defective positions are stored and the cast bar is cut into a predetermined length while removing only the defective portions by a cutting device.

[0055] Furthermore, in the ultrasonic flaw inspection device 10, the continuous cast bar S can be subjected to ultrasonic flaw inspection while being moved. Therefore, inspection target portions include no end surface, which in turn means that there is no dead zone on end surfaces since there is no end surface in the inspection target portion. As a result, short pieces obtained by cutting after the inspection can be treated as pieces inspected up to the end surfaces.

**(SECOND EMBODIMENT)**

[0056] The ultrasonic flaw inspection device 10 of the first embodiment uses a water tank and is advantageous in that it is easy to submerge the cast bar and a sufficient amount of contact medium can be secured.

[0057] However, the ultrasonic flaw inspection method of the present invention can allow inspection using cooling water supplied to a cast bar from a casting mold of a horizontal continuous casting device, without using a water tank. Using cooling water simplifies the structure of the inspection device.

[0058] Fig. 5 shows a horizontal continuous casting device

30 and an ultrasonic flaw inspection device 40 installed immediately at the downstream side of the casting mold.

[0059] In the continuous casting device 30, the molten metal M flows into a cylindrical casting mold 33 from a tundish 31 via a molten metal nozzle 32. At the outlet side of the casting mold 33, a cooling water supplying passage 34 for supplying cooling water 35 to the periphery of the continuous cast bar S is provided. The discharge opening 34a of the cooling water supplying passage 34 is formed into an annular shape surrounding the continuous cast bar S, and directed in the casting direction of the continuous cast bar S. The cooling water 35 ejected from the discharge opening 34a is supplied to the entire periphery of the continuous cast bar S, and flows in the casting direction on the surface of the continuous cast bar S which is being continuously cast to cool the continuous cast bar S.

[0060] The ultrasonic flaw inspection device 40 is equipped with an annular dam-like member 42 having a through-hole 41 through which the continuous cast bar S is loosely inserted and two phased array type probes 1 and 2. The dam-like member 42 is fixed to a platform via a supporting leg 43 at a height level of the continuous cast bar S, and the inner diameter of the through-hole 41 is formed to be larger than the outer diameter of the continuous cast bar S. Consequently, the continuous cast bar S which is being continuously cast travels through the through-hole 41 without contacting the periphery of the through-hole 41, and the cooling water 35 flows through the gap between the outer peripheral surface

of the continuous cast bar S and the inner peripheral surface of the through-hole 41.

[0061] In the inspection device 40, the cooling water 35 discharged from the discharge opening 34a and flowed in the casting direction on the surface of the continuous cast bar S hits against the dam-like member 40, and a part of the cooling water is accumulated at the upstream side of the dam-like member 42, and the rest thereof flows through the through-hole 41.

[0062] The two phased array type probes 1 and 2 are supported by supporting members (not illustrated) with the tip end portions arranged in the deep cooling water accumulated at the upstream side of the dam-like member 42 at a predetermined arrangement angle $\alpha$. The inspection result is outputted to the signal processor 20 and then to the ultrasonic inspection judgment device 21. The ultrasonic inspection judgment device 21 determines presence or absence of defects and/or flaws based on the inputted signal to decide the quality of the continuous cast bar S, and the judgment result will be fed back to the casting conditions.

[0063] The ultrasonic flaw inspection device 40 uses the cooling water for cooling the casting mold 33 as contact medium, and therefore no transferring equipment for transferring the cast bar S to the inspection device is required. This simplifies the peripheral devices for inspection.

[0064] Furthermore, the ultrasonic flaw inspection can be performed by arranging the phased array type probes 1 and 2 on the peripheral surface of the through-hole 41 of the dam-like member

40.

[ULTRASONIC FLAW INSPECTION IN CONSISTENT CONTINUOUS OPERATION]

The ultrasonic flaw inspection method of the present invention can be applied not only to inspection of a continuous cast bar immediately after the casting, but also can be applied to inspection of a continuous cast bar at any step between consistent continuous operation steps until the cast bar is shipped after various processing steps including cutting, heat treatment, and peeling of the cast bar. Furthermore, in the case of manufacturing a forged product by consistently performing from the continuous casting to production of a forged product after the casting, the ultrasonic flaw inspection can be performed immediately after casting or between arbitrary steps.

[0065] Figs. 6A to 6C show a process flow of a consistent production from casting to forging.

(FIG. 6A)

A long continuous cast bar obtained by horizontal continuous casting is cut into a plurality of short pieces, and the short piece is heat treated for homogenization, and then peeling is performed to eliminate the black skin, or hard casting skin, of the surface layer portion. The short piece from which the black skin was eliminated is shipped after the appearance inspection. Alternately, the short piece after the appearance inspection is subjected to forging. The forging step includes cutting (production of a preliminary product), preliminary heating, and forge forming.

[0066] In the consistent continuous operation, the ultrasonic flaw inspection can be performed between any steps, and the inspection can be performed at a single or plural portions. The reference symbol "K" denotes a process for inspecting a travelling continuous cast bar which is being cast from the casting mold of the horizontal continuous casting device, and the inspection can be performed by either the ultrasonic flaw inspection device 10 equipped with a water tank or the ultrasonic flaw inspection device 40 using cooling water of the casting mold. The reference symbol "L" denotes a process for inspecting a long continuous cast bar cut into short pieces in a state in which a black skin is not eliminated. The reference symbol "M" denotes a process for inspecting a short piece after peeling from which the black skin was eliminated. In the processes "L" and "M," an ultrasonic flaw inspection device 10 equipped with a water tank can be used.

(FIG. 6B)

A long continuous cast bar obtained by horizontal continuous casting is cut into a plurality of short pieces, and subjected to peeling to eliminate the black skin of the surface layer. The short piece from which the black skin was eliminated is heat treated for homogenization, and further preheated to perform a forging process.

[0067] In the consistent continuous operation, the ultrasonic flaw inspection can be performed at a single or plural portions between arbitral processes. The reference symbols "K," "L," and "M" shown in Fig. 6B are the same as the inspection processes "K,"

"L," and "M" shown in Fig. 6A.

(FIG. 6C)

A long continuous cast bar produced by horizontal continuous casting is cut into a plurality of short pieces, heat treated for homogenization, and then subjected to peeling to eliminate the black skin of the surface layer. The short piece from which the black skin was eliminated is subjected to forging.

[0068] In the consistent continuous operation, the ultrasonic flaw inspection can be performed at a single or plural portions between arbitral processes. The reference symbols "K," "L," and "M" shown in Fig. 6C are the same as the inspection processes "K," "L," and "M" shown in Fig. 6A.

[0069] As explained above, by performing ultrasonic flaw inspection in a continual production performed from continuous casting to forging, high quality forged products can be manufactured in an efficient manner.

[0070] The inspection method for a continuous cast bar according to the present invention can be applied to casting of all kinds of metals. For example, it can be applied to continuous casting of aluminum or aluminum alloy.

[0071] This application claims priority to Japanese Patent Application No. 2007-336453 filed on December 27, 2007, the entire disclosure of which is incorporated herein by reference in its entirety.

[0067] It should be understood that the terms and expressions used herein are used for explanation and have no intention to be

used to construe in a limited manner, do not eliminate any equivalents of features shown and mentioned herein, and allow various modifications falling within the claimed scope of the present invention.

## INDUSTRIAL APPLICABILITY

[0068] According to the ultrasonic flaw inspection method for a cast bar according to the present invention, since a longitudinal inclined angle wave or longitudinal vertical wave are used as incident light, and a plurality of phased array type probes complement uninspected regions with each other, an entire region of the cast bar circular in cross-section can be inspected. By using this inspection method, healthy cast bars can be manufactured efficiently.

## CLAIMS

1. An ultrasonic flaw inspection method for a cast bar,

wherein, in performing ultrasonic flow inspection by arranging a plurality of phased array type probes in a circumferential direction of the cast bar circular in cross-section at a predetermined angle,

one of the phased array type probes and the other phased array type probe are arranged such that an uninspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the one of the phased array type probes is complemented with an inspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the other phased array type probe.

2. The ultrasonic flaw inspection method as recited in claim 1, wherein the two phased array type probes are arranged at an arrangement angle $\alpha$ which satisfies following two formulas:

$$2 \times (180° - 2\theta_2 + \theta_3) \leqq \alpha \leqq 2\theta_2 - \theta_3 - \theta_4$$

$$180° - [3\theta_3 + 3(180° - 2\theta_2)] \geqq \theta_4$$

where

$\theta_2$: effective inclined angle of a phased array type probe

$\theta_3$: central angle of OP

$\theta_4$: 1/2 of a central angle of a dead zone of a vertical incident wave of the phased array type probe

O: incident point of the vertical incident wave of the phased array type probe

P: incident point of an inclined angle incident wave at the maximum scanning angle of the phased array type probe.

3. The ultrasonic flaw inspection method for a cast bar as recited in claim 2, wherein the two phased array type probes are arranged so that the incident waves travel downward.

4. The ultrasonic flaw inspection method for a cast bar as recited in any one of claims 1 to 3, wherein a plurality of phased array type probes are arranged at a vicinity of a casting mold outlet of a horizontal continuous casting mold and ultrasonic flaw inspection is continuously performed for a continuous cast bar which is being continuously cast.

5. The ultrasonic flaw inspection method as recited in claim 4, wherein the continuous cast bar is loosely inserted into a through-hole of a dam-like member arranged apart from the casting mold outlet at a downstream side to interrupt flow of the cooling water, and

wherein the phased array type probes are arranged in a state in which the probes are in contact with the cooling water that the flow is interrupted.

6. An ultrasonic flaw inspection device for a cast bar,

comprising a plurality of phased array type probes arranged in a circumferential direction of the cast bar circular in cross-section, and

one of the phased array type probes and the other phased array type probe are arranged such that an uninspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the one of the phased array type probes is complemented with an inspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the other phased array type probe.

7. The ultrasonic flaw inspection device for a cast bar as recited in claim 6, wherein the two phased array type probes are arranged at an arrangement angle $\alpha$ which satisfies following two formulas:

$$2 \times (180° - 2\theta_2 + \theta_3) \leqq \alpha \leqq 2\theta_2 - \theta_3 - \theta_4$$

$$180° - [3\theta_3 + 3(180° - 2\theta_2)] \geqq \theta_4$$

where

$\theta_2$: effective inclined angle of a phased array type probe

$\theta_3$: central angle of OP

$\theta_4$: 1/2 of a central angle of a dead zone of a vertical incident wave of the phased array type probe

O: incident point of the vertical incident wave of the phased array type probe

P: incident point of an inclined angle incident wave at the

maximum scanning angle of the phased array type probe.

8. A consistent manufacturing method for a forged product, wherein, in a consistent production method of a cast product in which a continuous cast bar circular in cross-section which is being continuously cast from a casting mold outlet of a horizontal continuous casting device is subjected to short-length cutting, peeling, and heat-treatment in an arbitrary order, and subsequently subjected to forging, ultrasonic flaw inspection is performed immediately after casting or between arbitrary processes, and

wherein the ultrasonic flaw inspection is performed by arranging a plurality of phased array type probes in a circumferential direction of the cast bar circular in cross-section at a predetermined angle, and arranging one of the phased array type probes and the other phased array type probe such that an uninspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the one of the phased array type probes is complemented with an inspected region by a longitudinal inclined angle wave and a longitudinal vertical wave of the other phased array type probe.

9. The consistent manufacturing method for a forged product as recited in claim 8, wherein the ultrasonic flaw inspection is performed by arranging two phased array type probes at an arrangement angle $\alpha$ which satisfies following two formulas:

$$2 \times (180° - 2\theta_2 + \theta_3) \leqq \alpha \leqq 2\theta_2 - \theta_3 - \theta_4$$

$180° - [3\theta_3 + 3(180° - 2\theta_2)] \geqq \theta_4$

where

$\theta_2$: effective inclined angle of a phased array type probe

$\theta_3$: central angle of OP

$\theta_4$: 1/2 of a central angle of a dead zone of a vertical incident wave of the phased array type probe

O: incident point of the vertical incident wave of the phased array type probe

P: incident point of an inclined angle incident wave at the maximum scanning angle of the phased array type probe.