73-625 SR

XR 3,850,027

United States
Nakanishi et al.

X 3063D
X 3111S

[11] **3,850,027**
[45] **Nov. 26, 1974**

[54] **IMMERSION ULTRASONIC INSPECTION SYSTEM OF THE WHOLE SURFACE OF ROLLED FLAT BAR**

[75] Inventors: **Akito Nakanishi**, Nishinomiya; **Hisashi Nakazawa**, Akashi; **Kazuyoshi Yamashima**, Nishinomiya; **Toshio Shiraiwa**, Ikoma; **Hisao Yamaguchi**, Akashi, all of Japan

[73] Assignee: **Sumitomo Metal Industries, Ltd.**, Osaka, Japan

[22] Filed: **Mar. 2, 1973**

[21] Appl. No.: **337,711**

[30] **Foreign Application Priority Data**

Mar. 9, 1972 Japan.............................. 47-23567

[52] **U.S. Cl.**............................... **73/67.8 S,** 73/105
[51] **Int. Cl.**.. **G01n 29/04**
[58] **Field of Search**............ 73/105, 67.8 S, 67.8 R, 73/71.5 U, 67.9, 67.7

[56] **References Cited**

UNITED STATES PATENTS

2,524,208	10/1950	Piper	73/67.6
3,224,254	12/1965	Loving	73/67.8 S X
3,285,059	11/1966	Bogle	73/67.9
3,364,732	1/1968	Sasaki	73/67.8 S

OTHER PUBLICATIONS

"Surface Waves at Ultrasonic Frequencies" by Cook et al., ASTM Bulletin, May 1954, pages 81–84.

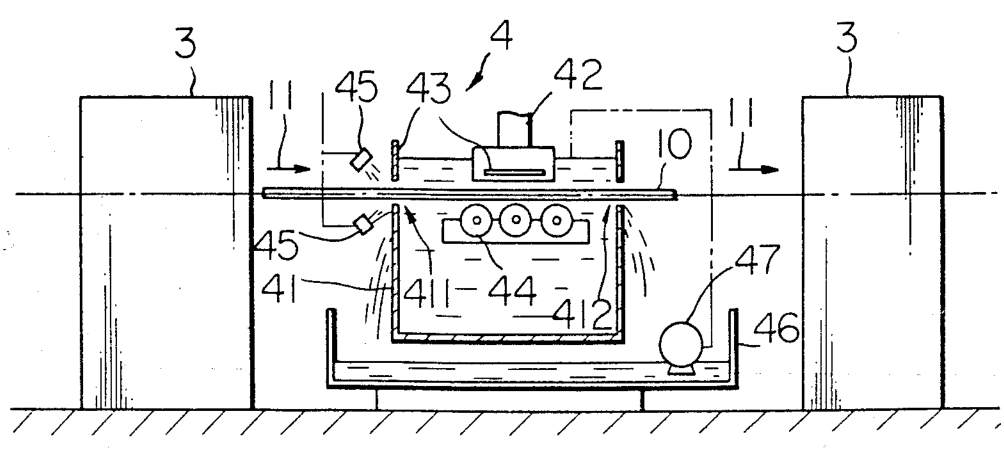
Primary Examiner—James J. Gill
Attorney, Agent, or Firm—Kurt Kelman

[57] **ABSTRACT**

The immersion ultrasonic inspection system inspects the whole surface of a rolled flat bar specimen including flat and end portions thereof by immersing the specimen and probes in water and applying surface wave to the specimen by a plurality of probes disposed in the front and back sides of the specimen at the different points with inclination to the surface of the specimen.

8 Claims, 16 Drawing Figures

attenuation,
flaw size
X [illegible]
[illegible] 3047
X a.g.c



S

Fig. 1

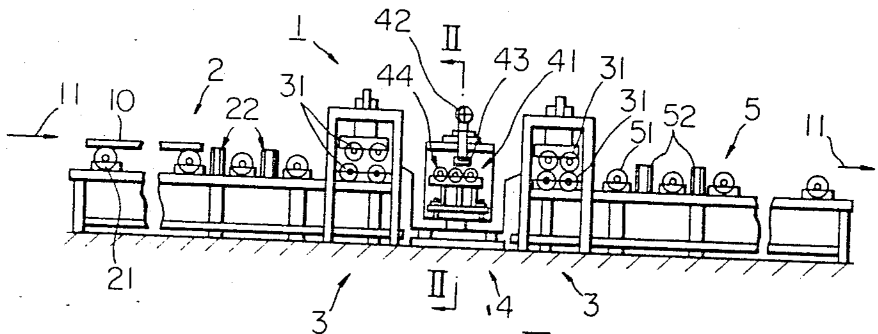


Fig. 2

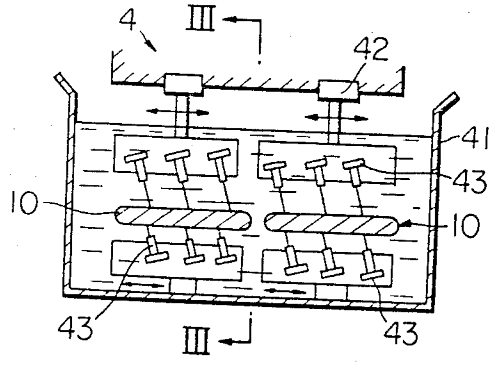


Fig. 3

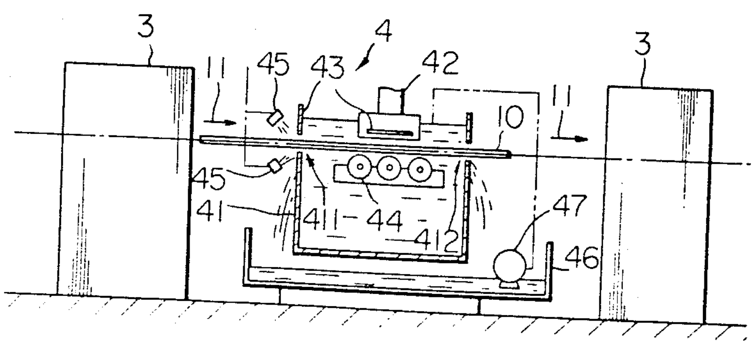


Fig. 4A

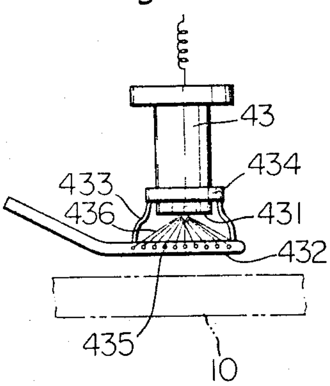


Fig. 4B

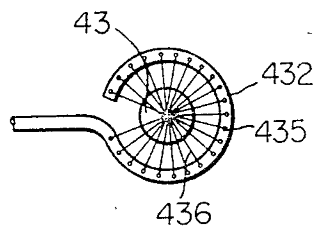


Fig. 4C

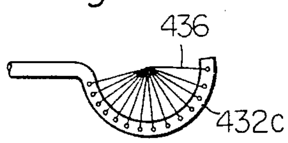


Fig. 4D

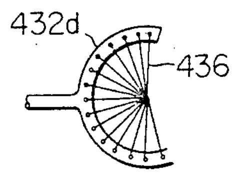


Fig. 5

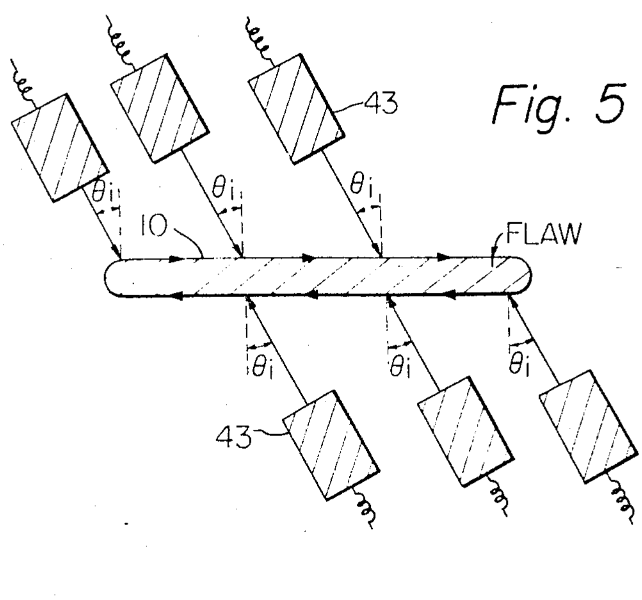


Fig. 6

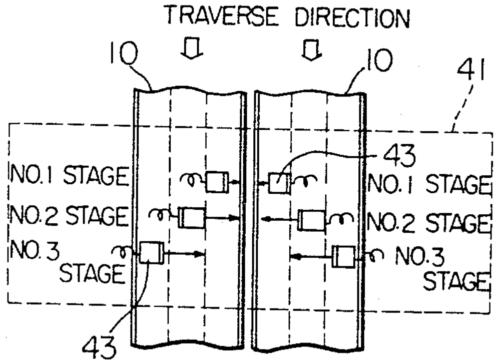


Fig. 7

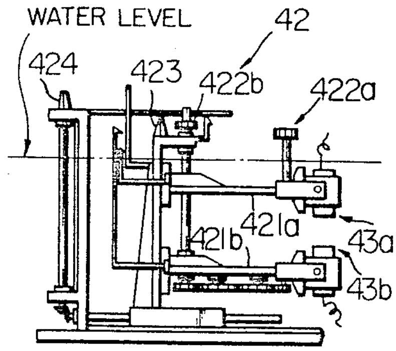


Fig. 8

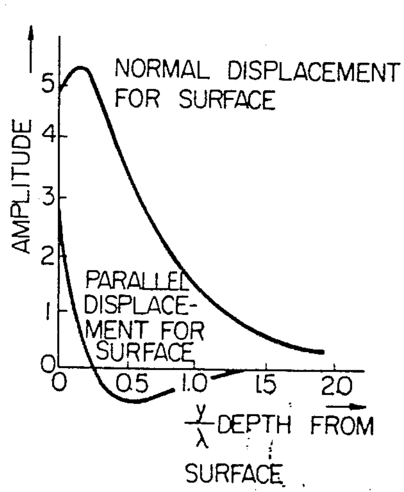


Fig. 9

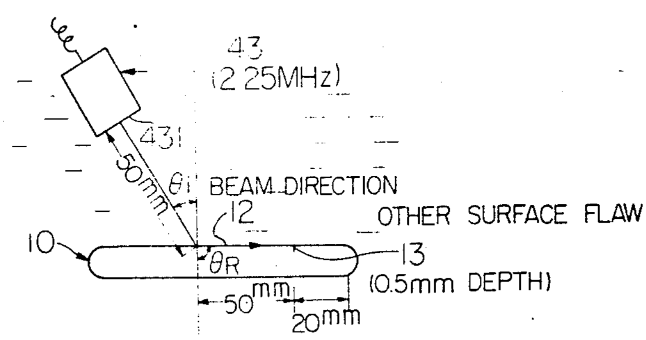

43
(2.25MHz)
431
50mm
θi
BEAM DIRECTION
12
OTHER SURFACE FLAW
10
θR
13
(0.5mm DEPTH)
50mm
20mm

Fig. 10

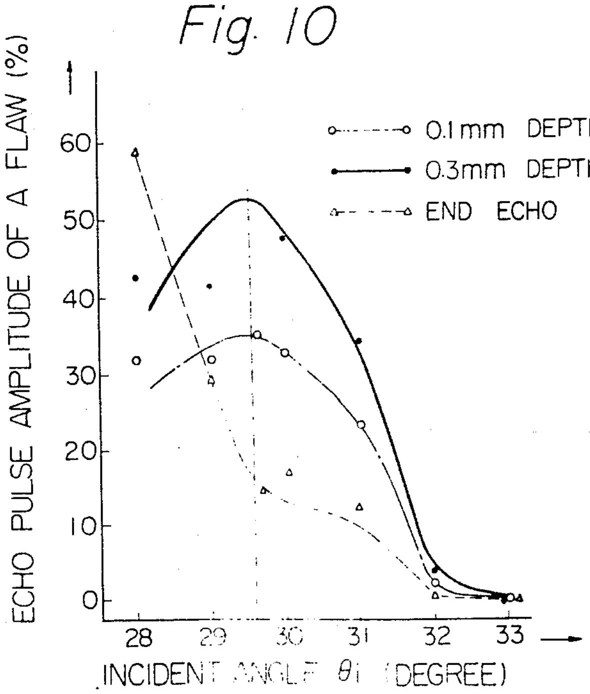

ECHO PULSE AMPLITUDE OF A FLAW (%)
60
50
40
30
20
10
0
0.1mm DEPTH
0.3mm DEPTH
END ECHO
28
29
30
31
32
33
INCIDENT ANGLE θi (DEGREE)

Fig. 11

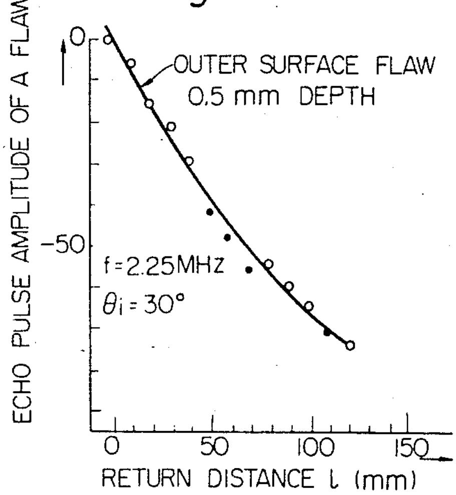


Fig. 12

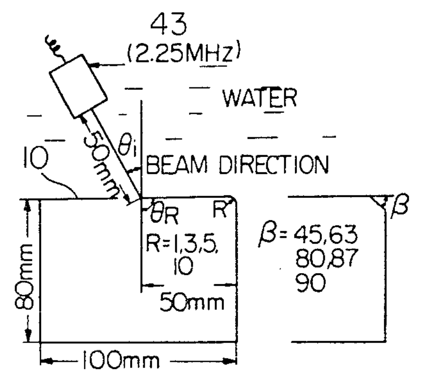
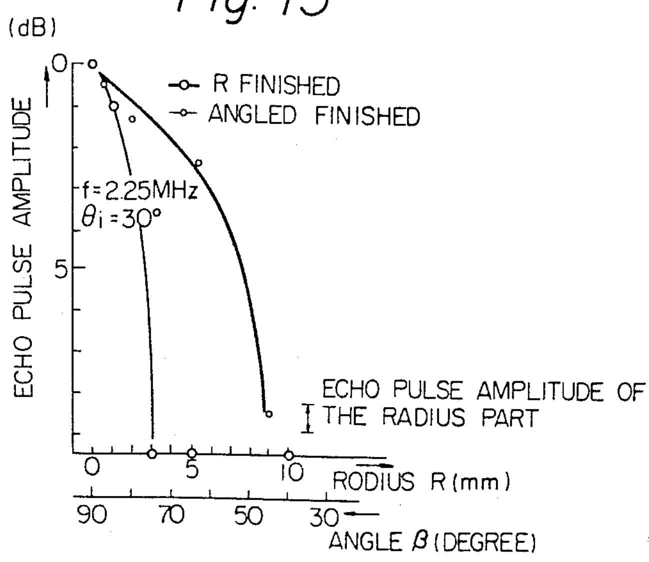


Fig. 13



IMMERSION ULTRASONIC INSPECTION SYSTEM OF THE WHOLE SURFACE OF ROLLED FLAT BAR

BACKGROUND OF THE INVENTION

The present invention relates to a system for detecting surface flaws over the whole surface of a flat bar including flat and end portions thereof using surface wave propagation in an immersion ultrasonic inspection method.

With the development of the sutomobile industry the demand for rolled spring steel flat bars has increased and, at the same time, better quality and reliability have been required making precise and reliable inspection indispensable.

In detecting defects on the surface of rolled spring steel flat bars it has become a common practice to find flaws visually. Other methods, such as ultrasonic inspection and eddy current inspection, have been employed only in the limited region. Heretofore, however, an advanced inspection system capable of automatically inspecting the whole surface of the flat bar including the end portions thereof at high accuracy and at economical speed has not been developed in the art.

Accordingly, an object of this invention is to provide an immersion ultrasonic inspection system for automatically and efficiently inspecting the whole surface of the rolled flat bar including the flat and end portions thereof at high accuracy.

Another object of this invention is to increase the inspection accuracy by preventing bubbles from attaching to the surface of specimen by spraying water under pressure onto the whole surface of the specimen to forcibly prewet the whole surface immediately before introducing the specimen into immersion tank.

A further object of this invention is to increase the inspection accuracy by preventing bubbles from attaching to the ultrasonic transmitting and receiving surface of probes disposed within the immersion tank by spraying water under pressure onto the surface.

A still further object of this invention is to provide a probe positioner for freely controlling the distance, angle of inclination, horizontal and vertical positions of the probes disposed within the immersion tank.

SUMMARY OF THE INVENTION

From the fact that displacement energy of surface wave concentrates in the depth of several wavelengths from the surface of the flat bar, it is generally known that the inspection sensitivity is high for the flaw immediately below the surface and that the surface wave has a tendency to get around the end portions of the flat bar. Applying this phenomenon to immersion inspection, this invention has developed a high speed and stable immersion inspection system for detecting flaws on the whole surface of the rolled flat bar including rolled spring steel flat bar.

The immersion ultrasonic inspection system according to the present invention has an inlet table, side guide rollers, pinch rollers, a flaw detector (water tank, probe positioner, etc.), and an outlet table disposed in series on a transfer line of rolled flat bars of, for example, rolled spring steel flat bar. A specimen of the rolled flat bar is introduced into the immersion tank, probes are disposed in both front and back sides of the specimen in inclined relation thereto at respectively different points of incidence within the immersion tank, and a surface wave is applied to the specimen from the probes to detect flaws on the whole surface of the specimen including the flat and end portions thereof.

The specimen prewetting means according to this invention has a set of nozzles inclined from the upper and lower directions at the neighborhood of the specimen inlet of the immersion tank of the flaw detector. The prewetting means prevents bubbles from attaching to the surface of the specimen by spraying water under pressure onto the surface thereof from the nozzles. A tank for receiving water leaking from the nozzles and the immersion tank may be provided so that the received water is returned to the immersion tank by a suitable pump.

The bubble removing means of the immersion type probe according to this invention removes bubble attaching to the ultrasonic transmitting and receiving surface of the probe immersed in the water by spraying water under pressure onto the ultrasonic transmitting and receiving surface of the (immersion type) probe.

The probe positioner according to this invention having a set of probes spaced apart from and retained opposite to each other can control distance between the probes, vertical and horizontal positions and angles of inclination of the probes.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood from the following description taken in connection with the accompanying drawings in which:

FIG. **1** is a side view showing a schematic construction of the immersion ultrasonic inspection system according to the present invention;

FIG. **2** is a partial sectional view taken along the line II—II of FIG. **1**;

FIG. **3** is a schematic constructional view taken along the line III—III of FIG. **2**;

FIGS. **4A–4D** are a side view and plan views of the bubble removing means of the probe;

FIGS. **5** and **6** are schematic illustrations of the arrangement of the probes;

FIG. **7** is a side view of the probe positioner;

FIG. **8** is a graph explaining the energy displacement of surface wave;

FIG. **9** is a schematic illustration of the inclined disposition of the probe;

FIG. **10** is a graph showing the relation between the angle of inclination of the probe and the echo height;

FIG. **11** is a graph showing the relation between the inspection distance and the attenuation of echo;

FIG. **12** is a schematic illustration of an arrangement for testing the effect of the shape of the end of specimen on the end echo; and,

FIG. **13** is a graph showing the relation between the shape of the end of specimen and the echo height.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A preferred embodiment of the immersion ultrasonic inspection system according to the present invention will now be described. FIG. **1** is a side view showing a schematic construction of the immersion ultrasonic inspection system **1** comprising an inlet table **2**, a set of pinch rollers **3**, a flaw detector **4**, and an outlet table **5**.

A specimen **10** is transferred in the longitudinal direction **11** by transfer rollers **21** and side guide rollers **22** mounted on the inlet table **22** and reaches the first pinch rollers **3**, whereat the specimen **10** is controlled in horizontal position by side guide rollers **22** and controlled in vertical position and transferred to the flaw detector **4** to be described. The specimen **10** having passed the flaw detector **4** is received by the second pinch rollers **3** to be controlled in vertical position and then transferred to the succeeding outlet table **5**. The specimen **10** is further transferred in the longitudinal direction **11** by transfer rollers **51** and side guide rollers **52** mounted on the outlet table **5**.

In order to increase the inspection efficiency it is preferable to transfer in the longitudinal direction a plurality of specimens (two bars in this embodiment) disposed in parallel to each other. This is easily achieved by using the side guide rollers suitably.

The first and second pinch rollers **3** are in the same construction comprising a set of pinch rollers **31** vertically spaced from each other. The specimen **10** passes through the set of pinch rollers.

The flaw detector **4** comprises an immersion tank **41**, probe positioners **42**, probes **43**, and receiving rollers **44**. As shown in FIGS. **2** and **3**, two specimens **10** disposed in parallel are transferred from the first pinch rollers **3** to the flaw detector **4**, introduced into the immersion tank **41** through an inlet **411** and transferred out through an outlet **412**. In the immersion tank, the specimens **10** are supported by the receiving rollers **44** and immersed within the water, and are disposed, as shown in FIGS. **2** and **3**, so as to be detected from the upper and lower directions by a plurality of probes **43** which are, as detailedly described hereinbelow, adjustably mounted to the probe positioners **42**.

In the immersion ultrasonic inspection system using water as the medium of ultrasonic waves, specimens are introduced into the immersion tank and inspected within the water. When the specimen is introduced into the water at high speed, an air layer is formed between the specimen and the water making thereby projection of ultrasonic wave difficult and normal inspection impossible. Since ultrasonic surface wave reflects very sensitively minute roughness on the surface to be inspected, even the presence of a minute air bubble reflects ultrasonic surface wave. In the immersion tank, surface of the specimen is normally in the completely wet condition. Heretofore, however, when several small air bubbles are remaining attached on the surface, not only the surface flaws but also such air bubbles are detected thereby decreasing the inspection accuracy and to make the judgement of the flaws difficult.

Accordingly, it is essential to increase the affinity (or attachment) of the specimen for water by, for example, forcibly prewetting the whole surface of the specimen by spraying water under pressure onto the specimen before introducing the specimen into the immersion tank. Prewetting prevents the formation of an air layer between the surface of the specimen and water, attachment of air bubbles or other materials to the surface of the specimen and leakage of water of the tank through the specimen inlet of the tank.

In order to meet this necessity, in this invention, as shown in FIG. **3**, nozzles **45** are provided at the entrance side of the inlet **411** of the immersion tank **41** for spraying water under pressure toward said inlet **411** from the upper and lower directions. The water sprayed by the nozzles **45** wets both upper and lower sides of the specimen **10** when entering the immersion tank **41** after passing through the first pinch rollers **3**, while cleaning the dusts on the surface of the specimen away with its pressure. Accordingly, when the specimen **10** is introduced into the immersion tank **41**, the surface of the specimen **10** has the affinity for the water of the immersion tank and, therefore, is free from the attachment of air bubbles. At the same time, the water under pressure sprayed from the nozzles **45** prevents leakage of water from the inlet **411** of the immersion tank **41**.

The pressure of water about 3 – 5 Kg/cm^2 is sufficient for the function of the nozzles **45**. A portion of the sprayed water is transferred together with the specimen **10** into the immersion tank **41**. The rest of the water is, received by a tank **46** provided below the immersion tank **41**, and is recirculated by a circulating pump **47** into the immersion tank **41** together with the water overflowed from the tank **41**.

Further, in the immersion ultrasonic inspection system, air bubbles floating within the water or attached to the surface of the specimen frequently attached to the ultrasonic transmitting and receiving surface of the probe within the water causing decrease in inspection sensitivity and generation of noise resulting in decrease in accuracy or reliability of flaw detection. Accordingly, it is necessary to increase the reliability of the flaw detection by removing the air bubbles from the ultrasonic transmitting and receiving surface of the probe disposed within the immersion tank.

In the present invention, in order to meet this necessity, a ring-shaped nozzle pipe **432** is provided at the position opposite to and somewhat spaced from the ultrasonic transmitting and receiving surface **431** of the probe **43**, as shown in FIG. 4A. The ring formed at the leading end of the nozzle pipe **432** has a diameter somewhat larger than the outer diameter of the probe body **43** as shown in FIG. 4B, and is connected and supported at several points to a fixture **434** by supports **433** so that the center of the probe **43** is coaxial with the center of the ring formed by the nozzle pipe **432**. On the inner side of the ring of the nozzle pipe **432** there are provided a number of orifices **435** so that, during injection, water under pressure injected from the orifices **435** is uniformly applied to the ultrasonic transmitting and receiving surface **431** of the probe **43** disposed above the ring. Even when the probe **43** is operating to transmit and receive the ultrasonic waves, water under a predetermined pressure is continuously injected from the orifices **435** toward the central portion of the transmitting and receiving surface.

While the nozzle pipe **436** in the preferred embodiment of this invention is described to be a copper pipe of diameter about 5 – 6 mm having injection orifices of diameter about 1 – 1.5 mm, it is to be clearly understood that the nozzle pipe of this invention is not limited thereto or thereby. The nozzle pipe of this invention is not limited also in shape to the ring as shown in FIG. 4B. But it can be formed in semi-circle configuration as shown in FIGS. 4C and 4D or in any polygonshape as desired. In any of such shapes other than the ring, the effect similar to that of said embodiment can be achieved by applying water under pressure injected from the nozzle uniformly onto the ultrasonic transmitting and receiving surface of the immersion type probe.

Since the inspection system according to the present invention employs immersion ultrasonic inspection system, it is preferable to dispose the probes as shown in FIGS. **5** and **6** considering the attenuation of surface wave with distance within water. Namely, a plurality of probes (three probes in this embodiment) are disposed on the both front and back sides of the specimen **10** in inclined relation to the vertical direction by a predetermined angle θi as described in detail hereinbelow so that the full width of the specimen **10** can be covered by the probes.

Referring now to FIG. **7**, the construction of a probe positioner **42** for determining and maintaining the probes is described. A probe **43***a* for inspecting the front side and a probe **43***b* for inspecting the back side are attached respectively to support arms **421***a* and **421***b* spaced vertically from each other. The position of probes **43***a* and **43***b* are controlled in angle with respect to the vertical direction respectively by handles **422***a* and **422***b*, in vertical space therebetween by a handle **423**, and in horizontal position, namely the position in widthwise direction of the specimen by an handle **424**. It is preferable that the control of these angle of inclination, length of space, and vertical and horizontal positions is indicated in suitable scales. More detailed description of the probe positioner will be unnecessary to the skilled in the art in working this invention.

In FIG. **6**, there are shown three stages (No. **1**, No. **2**, and No. **3**) of the probe positioners **42** disposed along the advancing direction of the specimen **10**.

Now, the determination of angle of incidence of the probes is described.

From the fact that displacement energy of a surface wave generally concentrates in the depth of several wavelengths from the surface of the specimen as is obvious from FIG. **8**, it is known that the inspection sensitivity is high for the flaw immediately below the surface and that the surface wave has a characteristic property to get around beyond the corner of the specimen.

Taking advantage of this phenomenon, the inventors experimentally obtained the relation between the angle of incidence of ultrasonic wave and the echo height in the arrangement and dimension shown in FIG. **9** using lead zirconate vibrator of frequency 2.25 MHz having the diameter of 19 mm. In FIG. **9**, the probe **43** is inclined with respect to the vertical direction by the variable angle θi, the distance between the ultrasonic transmitting and receiving surface **431** of the probe **43** and the point of incidence **12** on the surface of the specimen **10** is fixed to **50** mm, the distance between the point of incidence **12** and the surface flaw **13** of the specimen **10** is determined as **50** mm, and the distance between the surface flaw **13** and the end portion of the specimen **10** is determined as **20** mm. The surface flaw **13** was made artificially by electrodischarge machining to the depth of 0.5 mm on the flat portion of the specimen.

The results of the experiment are shown in FIGS. **10** and **11**. As obvious from FIG. **10**, the detection accuracy is highest (or attenuation of echo is smallest) when the angle of incidence is about 30° and it corresponds well to the calculated value 30°7′ (30.11°). The angle at which reflection echo (noise echo) from the end portion is difficult to emit is 29°36′ (29.6°), a little acuter than the theoretical angle of incidence 30°7′ (30.11°). The attenuation of echo by a V notch **13** (see FIG. **9**) artificially made at **20** mm from the end portion is as shown in FIG. **11**. The echo attenuates functionally with distance and its attenuation is 6.16 dB/cm. However, this problem can be easily solved by using an automatic compensation circuit of attenuation by distance as described hereinbelow.

FIG. **13** shows the results of examination of the effect of the end reflected echo, namely using specimens having different end shapes (R finish and angle finish). As seen from FIG. **13**, the reflection is largest when the angle finish in 90°, and with R finish the surface wave propagates along the curvature and there is little reflection from the R portion. It is interesting to find that practical spring steel flat bars having the rolled R finish end and the angle finish end of 45° show almost the same reflection.

The inspection result detecting circuit to be connected to the probe, may be a known ultrasonic inspection circuit comprising a synchronous controller, a horizontal axis sweep, a pulse generator, a receiving amplifier, a cathode-ray tube, and a source of power. The results of detection are displayed on the cathode-ray tube or automatically recorded on for example a pen-writing oscillograph for observation.

An electric pulse synchronously controlled by the source frequency or any specific frequency is applied to the probe and converted into an ultrasonic pulse by an electrostriction vibrator of the probe, and the surface wave is made incident as an ultrasonic wave on the surface of the specimen. When the surface wave propagating on the surface of the specimen reaches a defect such as a flaw, it is reflected at that point and received by the probe, converted back into an electric pulse, amplified at the receiver, detected, indicated on the sweep trace of the cathode-ray tube, whereby the size of the flaw is detected. Since the attenuation of the surface wave is heavily influenced by the quality of the surface finish, flaw detection can be made easier by finishing the surface of the specimen well. In order to make the quantitative evaluation of the flaw further efficient, the detection circuit of the inspection system according to the present invention includes a distance compensation circuit and a level automatic control circuit for regulating the attenuation of the ultrasonic wave to uniformly evaluate the flaws detected at various portions of the specimen. In the system according to the present invention, when so desired, a delay circuit coupled with a marking device may be provided for automatically marking the flaw after the water is removed from the inspected specimen.

On the specimens having for example two different dimensions, namely 76.2 mm width × 11.35 mm thickness × 5,000 mm length and 88.9 mm width × 12.67 mm thickness × **5,000** mm length, an artificial flaw of 0.3 mm depth is made at the end portion. Thereafter, the inspection sensitivity of the system is established so that the echo height of the artificial flaw is 35 mm on the cathode-ray tube and continuous inspection is rendered at this sensitivity. Then, the inspection system can clearly detect natural flaws of 0.11 mm – 0.23 mm depth on the flat portion and artificial flaws of 0.08 mm – 0.44 mm depth on the end portion. Other smaller flaws such as lap and scratch of, for example, 50 μ depth can be detected by increasing the inspection sensitivity.

Table **1** shows the results of the practical flaw detection at the sensitivity described above.

Number of flat bars inspected	Number of flat bars accepted by Ultrasonic Insp.	Number of flat bars rejected by Ultrasonic Inspection					Remark
		Total	Crack	Lap	Scratch	Roll	
6,949	6,427	522	193	279	32	18	50 – 120 mm width

(Note) Three probes are applied each on the front and back sides of the specimens.

As is obvious from Table 1, in the inspection with the described sensitivity a harmful crack is not overlooked whereas harmful lap and roll flaws (not less than 0.2 mm in depth) are 100 percent detected though the detection sensitivity is varied with the shape of the flaws and the direction of incidence of ultrasonic wave. It may be added that 522 sheets of flat bars rejected by the ultrasonic inspection were all allowed after the flaws were removed by grinding.

The automatic surface flaw detection system of rolled steel bar according to the present invention has been used for inspecting flat bars having the dimension 50 – 120 mm width × 5 – 20 mm thickness × 4,000 – 6,500 length, at a highest rate 90 m/min (nominal rate: 60 – 70 m/min). In other words the system can continuously inspect two sheets of flat bars 6,000 mm long in eight seconds.

While the above preferred embodiment is shown used in an immersion tank, it is possible to achieve the same effect as in the above embodiment by using a laminar flow water nozzle instread of the immersion tank so that an ultrasonic transmitter (or a probe) is disposed within the laminar flow water nozzle and the ultrasonic wave is propagated within said nozzle.

As described above, in the method of the present invention, since the prewetting means of high power is provided prior to the partial immersion tank to increase the attachment of water to the rolled flat bar and simultaneously to cool it effectively, the present invention has an advantage that the specimens immediately after hot rolling can be continuously inspected in satisfactory condition without generating air bubbles or steam if only the surface temperature is not higher than 80°C without the necessity of waiting until the specimen is completely cooled.

According to the present invention, efficiency and accuracy of surface flaw detection of rolled flat bars such as spring steel flat bar for automobile construction are considerably increased, number of inspectors can be decreased, and inspection cost can be reduced.

While we have shown and described specific embodiments of our invention, it will be understood that these embodiments are merely for the purpose of illustration and description and that various other forms may be devised within the scope of our invention, as defined in the appended claims.

We claim:

1. An immersion ultrasonic inspection system which comprises in combination:

A. an immersion tank containing a liquid medium with means for maintaining a liquid level;

B. inlet means below the level of the liquid medium for introducing a flatbar to be inspected into the liquid medium and exit means below the level of the liquid medium for removing the flat bar therefrom;

C. liquid medium projecting means disposed for projecting liquid to said inlet for prewetting a flat bar passing therein;

D. a plurality of probes disposed on opposite sides of the flat bar to be inspected, said probes disposed within the immersion tank for projecting ultrasonic surface waves onto flat surfaces of the bar;

E. flat bar transferring means provided with guide rolls for transferring the bar to be inspected into the immersion tank and thereafter transferring the bar out of the immersion tank; and

F. electric circuit means for detecting the inspection results of the probes.

2. An immersion ultrasonic inspection system of the whole surface of rolled flat bar, according to claim 1, characterized in that the probes for particularly inspecting the end portion of the flat bar among the plurality of probes disposed both in the front and back sides thereof have the angle of incidence such that end echo is difficult to emit, preferably 29°36′ (29.6°).

3. An immersion ultrasonic inspection system of the whole surface of rolled flat bar, according to claim 1, characterized in that the flat bar transferring means is provided with a set of pinch rollers adjustably mounted thereon vertically spaced apart from each other and functions to control the vertical position of the flat bar transferred and introduce the flat bar properly into the immersion tank.

4. An immersion ultrasonic inspection system of the whole surface of rolled flat bar, according to claim 3, characterized in that the flat bar transferring means is provided with an inlet table and an outlet table, on said tables being disposed transfer rollers and side guide rollers with suitable distance therebetween for transferring a plurality of flat bars in parallel to each other simultaneously.

5. An immersion ultrasonic inspection system of the whole surface of rolled flat bar, according to claim 1, further comprising:

nozzles for spraying water under pressure toward the flat bar inlet of the immersion tank from the both upper and lower directions; and,

a pressure-regulatable feed-water system for feeding water under pressure continuously to the nozzles.

6. An immersion ultrasonic inspection system of the whole surface of rolled flat bar, according to claim 1, further comprising a ring-shaped nozzle mounted around each probe, said nozzle having a number of injection orifices arranged so that the water under pressure injected from the orifices is focused uniformly onto the ultrasonic transmitting and receiving surface of the immersion probe, and said nozzle being continuously supplied with water under pressure from the pressure-regulatable feed-water system.

7. An immersion ultrasonic inspection system of the whole surface of rolled flat bar, according to claim **6**, characterized in that the ring-shaped nozzle is formed in a semi-circle.

8. An immersion ultrasonic inspection system of the whole surface of a rolled flat bar according to claim **1** wherein a set of upper and lower probes are mounted each onto support arms movably spaced vertically apart, means disposed for regulating the angle of the probes in the vertical direction relative a bar passing therebetween, and means for positioning the probes in the horizontal direction relative a bar passing therebetween.

* * * * *