KAWASAKI STEEL TECHNICAL REPORT
No.24 (April 1991)

Development of Multiprobe Type Weld Flaw Monitor for ERW Pipe Mill

Hiroaki Kondo, Tadashi Okumura, Osamu Shinshi

Synopsis :
Ultrasonic inspection system has generally been installed for quality assurance of a longitudinal weld line in the ERW pipe mill. Recently, manufacturing lines tend to change to fully automated factory. Accordingly, it is necessary to automate the conventional ultrasonic inspection system with regard to size arrangements, calibration, and to free the ultrasonic inspection line from tracking on the weld line. As a result of research, the authors have created a new-concept-based inspection method that is named the "Multiprobe method." And, the equivalence of inspection accuracy between this new method and the conventional method were confirmed experimentally. This new weld flaw monitor system by the multiprobe method is currently in operation at Kawasaki's medium diameter ERW pipe mills of Chita Works, thereby contributing to realizing a fully automated manufacturing system.

The body can be viewed from the next page.

Development of Multiprobe Type Weld Flaw Monitor for ERW Pipe Mill*


Hiroaki Kondo
Staff Assistant Manager, Equipment & Engineering Sec., Chita Works


Tadashi Okumura
Staff Manager, Equipment & Engineering Sec., Chita Works


Osamu Shinshi
Assistant Manager, Welded Pipe Sec., Chita Works

Synopsis:

Ultrasonic inspection system has generally been installed for quality assurance of a longitudinal weld line in the ERW pipe mill. Recently, manufacturing lines tend to change to fully automated factory. Accordingly, it is necessary to automate the conventional ultrasonic inspection system with regard to size arrangements, callibration, and to free the ultrasonic inspection line from tracking on the weld line. As a result of research, the authors have created a new-concept-based inspection method that is named the "Multiprobe method". And, the equivalence of inspection accuracy between this new method and the conventional method were confirmed experimentally. This new weld flaw monitor system by the multiprobe method is currently in operation at Kawasaki's medium diameter ERW pipe mills of Chita Works, thereby contributing to realizing a fully automated manufacturing system.

1 Introduction

Great progress has been made in manufacturing techniques for ERW pipe, particularly in roll-forming and welding techniques. Further, improvement in steelmaking and continuous casting techniques has enhanced the quality of the steel plates supplied as material for ERW pipe, and the occurrence of flaws in the pipe body is decreasing. However, a manufacturing technique which will completely eliminate flaws at the weld seam has not yet been perfected, and equipment for nondestructive inspection of the weld seam, that is, NDI (nondestructive inspection) equipment, is used to guarantee weld quality. NDI includes ultrasonic inspection techniques that permit continuous longitudinal monitoring of all weld sections. For intermediate-size ERW pipe, the "seam UT" (ultrasonic tester for the weld seam) is commonly used. The manufacturing process of ERW pipe is shown in **Fig. 1**.

Recently, FA methods[1,2] have been widely adopted in ERW pipe manufacturing lines to improve productivity, and similar efforts are being made at Chita Works. To realize FA, complete automation of the seam UT process, including automation of the equipment set-up for various product sizes, is indispensable. However, it is difficult to realize an effective combination of FA and existing seam UT techniques since, for example, automatic positioning of the ultrasonic inspection probe to match the dimensions of the pipe requires a complicated mechanism and control unit, with an adverse effect on flaw detectability and reliability.

Impediments to the application of FA to seam UT include: ① Probe set-up following changes in pipe wall thickness, ② the time required for calibration using a test piece, ③ the necessity of seam tracking, and ④ operation of the equipment in general. The authors therefore examined seam UT techniques based on a new concept which simultaneously eliminates these problems, and conceived the "multiprobe system" which is the subject of this paper. Weld flaw monitoring with the multiprobe system offers flaw detectability equal or superior to existing seam UT and solves the problems associated with FA application. At this stage, it can be said that for the first time a simple NDI architecture suitable for FA application have been realized.

This report describes the technical basis of the multiprobe system, and describes peripheral techniques which were developed for the practical application of weld flaw monitoring based on the new concept.

* Originally published in *Kawasaki Steel Giho*, 22(1990)1, pp. 24–28

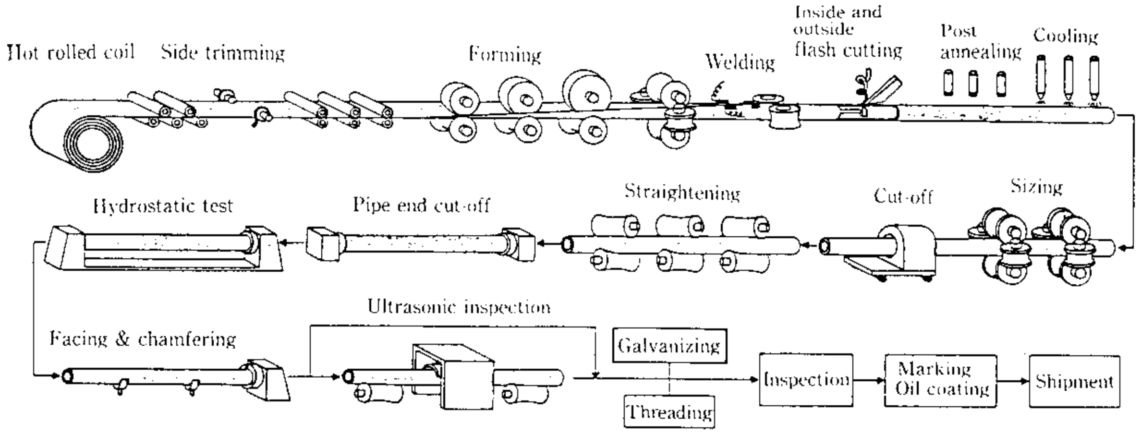


Fig. 1 Manufacturing process of 20-in. ERW pipe

2 Conventional Ultrasonic Testing Techniques[3)]

An angle beam technique is conventionally used for the ultrasonic testing of steel pipe. In this method, ultrasonic beams propagate through the interior of the inspected material, and repeated reflections permit flaw detection in the wall thickness direction. In addition, since it is possible to position the probe at a location removed from the material being inspected, ultrasonic testing can be used for flaw detection of high-temperature materials such as the weld seam of ERW pipe. **Figure 2** shows the relationship between the probe-to-weld distance and echo height obtained from the reflection source of ultrasonic waves (distance amplitude characteristic) in the angle beam technique.

However, the ultrasonic wavelength is ordinarily 4 to 5 mm, and is given a sharp beam spread. If the distance between the flaw and the probe changes even slightly, the echo height will therefore fluctuate greatly, and even if a flaw exists, an echo will not always be generated.

For this reason, conventional seam UT for ERW pipe uses the probe arrangement shown in **Fig. 3**. The total cross section of the weld in the wall thickness direction is divided into the outside part, inner part and inside part, and ultrasonic beams are irradiated on the respective sections.[4)] As the pipe wall thickness increases, the number of probes must naturally be increased.

Since conventional seam UT for ERW pipe uses this flaw detection method, it suffers the following problems, which prevent effective application of FA techniques:

(1) When set-up for a new size is necessary, the positions of all probes must be changed to positions corresponding to pipe wall thickness, as shown in Fig. 2. Positioning accuracy is ±2 mm, but in view of the environment of the manufacturing line, significantly higher precision is demanded.

(2) After the seam UT set-up is completed, it is necessary to calibrate the unit for the distance-related attenuation characteristics of ultrasonic waves using a test piece with an artificial flaw. Since compensation is required for all probes, the calibration process ordinarily requires a period of 15 to 20 min.

(3) When the manufacture of ERW pipe resumes after set-up, the weld line sometimes shifts within the

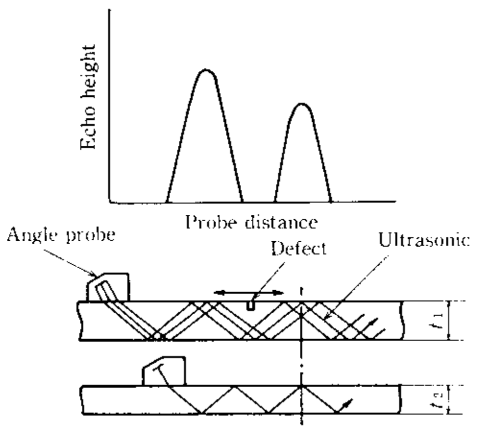


Fig. 2 Distance amplitude characteristic of conventional angle beam technique

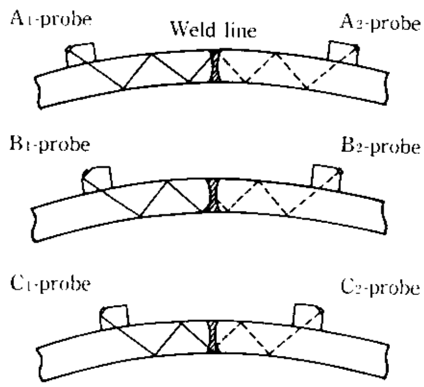


Fig. 3 Probe arrangement of conventional ultrasonic tester

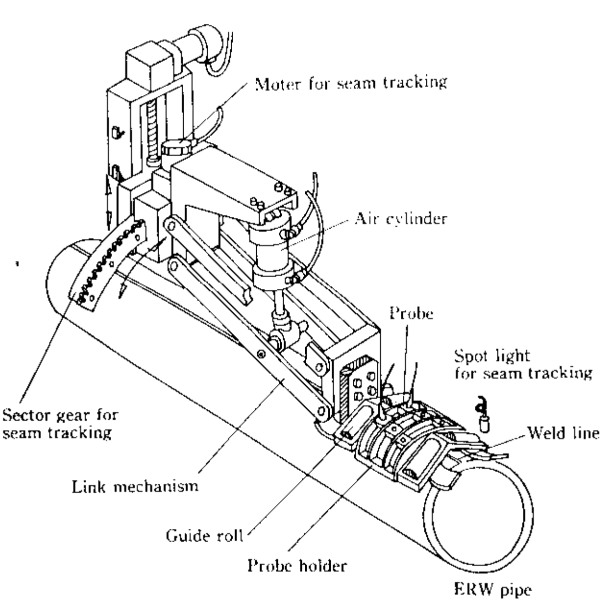


Fig. 4 Schematic mechanism of conventional ultrasonic tester for ERW pipe

range of plus-minus several mm due to operating conditions. As a result, the seam UT must be made to follow the weld line within an accuracy ±2 mm, either by a manual guiding device using a spot light or by automatic guiding device[5], in a procedure known as seam tracking.

A schematic diagram of the mechanism of a conventional seam UT device is shown in **Fig. 4**.

3 Development of Ultrasonic Testing System of Multiprobe Method

3.1 Design of Multiprobe Method

To compensate for the weak point of the distance amplitude characteristics of the conventional angle beam technique, a method using multiple probes, shown in Fig. 3, was adopted in an improved version of the conventional seam UT. Although the increase in the number of probes solved the distance amplitude characteristic problem, the new system had the disadvantages of more complicated set-up and calibration. Further, in manual flaw detection, the zigzag scanning method of flaw detection was adopted, in which the weak point of distance amplitude characteristics was solved by changing the distance between the probe and weld line, but this, of course, fails to meet the fundamental need for automation.

The distance amplitude characteristics of the angle beam technique are almost entirely determined by the angle of refraction of the angle probe and the beam width. In the weld inspection of ERW pipe, a refraction angle of 45° is generally used, taking into consideration the flaw detectability of hook cracks, which are a defect

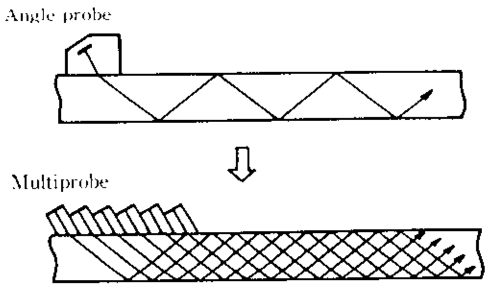


Fig. 5 Principle of multiprobe method

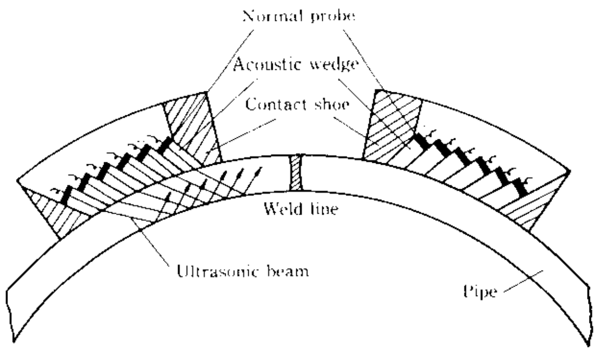
peculiar to ERW pipe.[3] To improve distance amplitude characteristics without changing the refraction angle, it is therefore necessary to widen the beam width.

The beam width can be expanded either by increasing the size of each transducer or by increasing the number of transducers. Larger transducers are already in practical application,[6] but the expansion of the transducer size, ncessarily causes significant differences within the acoustic wedge in the propagation distances of the ultrasonic beams transmitted from the various parts of the transducer. Since the attenuation factor of the acrylic resin used in the acoustic wedge is about 3 dB/cm, significant attenuation differnces will result from these propagation distance differences. Further, because the transducer size must be increased in proportion to pipe wall thickness, the wall thicknesses to which this method is applicable are limited. It is feared that the detectability of small flaws may also decline as the size of the transducers is increased.

An alternate solution developed by the authors is bundled ultrasonic beams with equal refraction angles, as shown in **Fig. 5**. The improvement in distance amplitude characteristics with this concept was analyzed by ultrasonic simulation[7] using a personal computer, and significant improvement was found when the transducer size was set at several millimeters and the number of transducers was increased so that the bundled ultrasonic beams had at least one skip or its equivalent. However, the conventional angle beam probe is not capable of receiving bundled ultrasonic beams, because its external length is 20 to 30 mm. In consideration of the fact that at minimum a transducer (or normal probe) and acoustic wedge are required, the authors designed a compact rectangular normal probe and acoustic wedge.

A multiprobe method based on this new concept was developed, as shown in **Fig. 6**. The actual appearance of the unit is shown in **Photo 1**. Installation of the acoustic wedge in front of the rectangular normal probe results in a combination unit which functions as a single angle beam probe, while the array-like arrangement of these compact angle beam probes around the circumference of the material to be inspected makes it possible to obtain bundled ultrasonic beams having equal refraction angles.

Fig. 6 Cross-sectional figure of multiprobe method



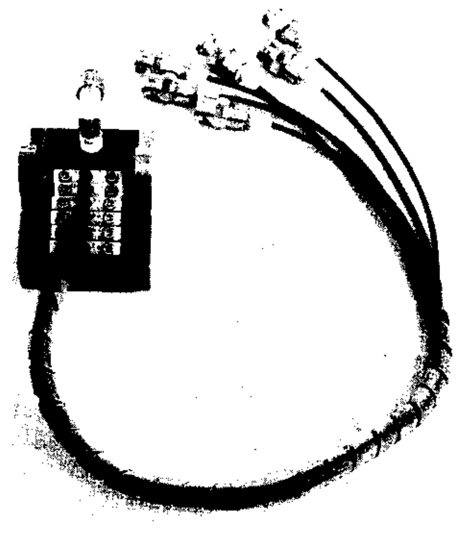


Photo 1 Appearance of multiprobe

3.2 Evaluation of Detectability

3.2.1 Distance amplitude characteristics

Using the newly developed multiprobe, the distance amplitude characteristics of a N-10 notch (a notch 10% of the depth of the pipe wall thickness) machined on the outer surface of an ERW pipe measuring 406.4 mm in outer diameter (OD) and 9.52 mm in wall thickness (WT) was investigated. The results are shown in **Fig. 7**. The distance amplitude characteristics of a single probe show, as mentioned earlier, a peak echo at the skip point, which is characteristic of the angle beam method. When a probe distance of 55 mm was used as a reference, echo height fluctuations of 15 dB/$\pm$10 mm were observed. However, as the number of probes increases, fluctuation of distance amplitude characteristics decreases, and when six probes are used, echo height fluctuation is reduced to $\pm$1.4 dB/$\pm$10 mm, clearly indicating that even if the distance between the probe and the weld line fluctuates, echo height varies only slightly with the multiprobe design.

Figure 8 shows the distance amplitude characteristics of the multiprobe device with various types of artificial

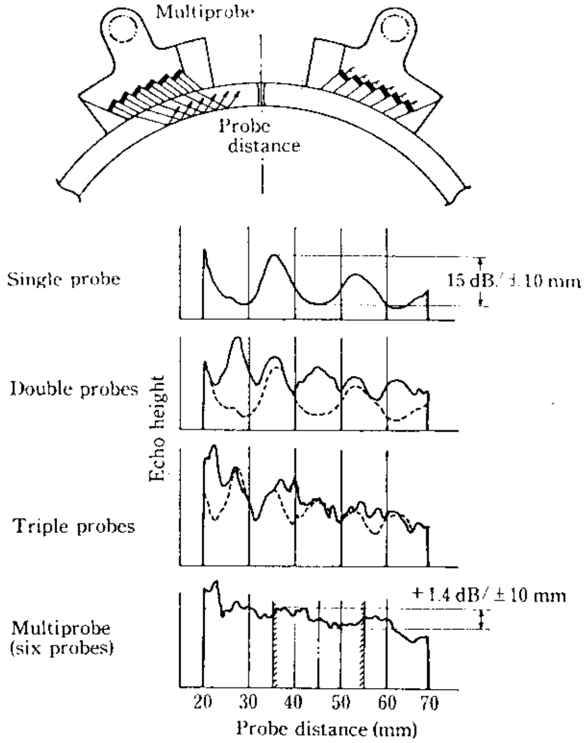


Fig. 7 Distance amplitude characteristics

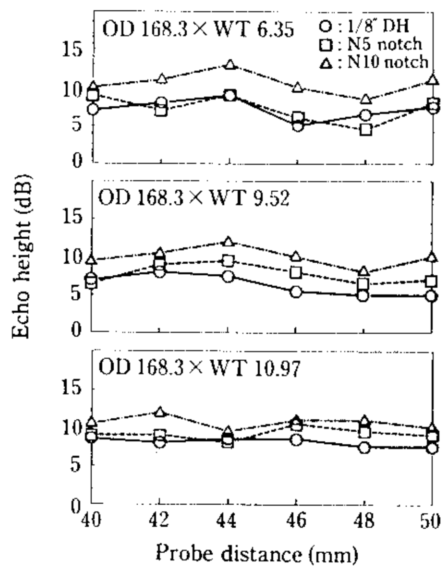


Fig. 8 Distance amplitude characteristics of multi-probe method

flaws machined on ERW pipes measuring OD 168.3 mm × WT 6.35, 9.52, and 10.97 mm. In all cases (3.2 mmϕ drilled hole, N-5 notch, and N-10 notch), changes in echo height with distance fluctuation were within $\pm$2 dB, indicating precisely the fact that, as desired, bundled ultrasonic beams having equal refraction angles are obtained. Since there is no peak phenomenon in echo height from the flaw when multiprobes are used, there is no necessity of tracking the weld line for positional fluctuations and satisfactory results can be realized merely by setting the probes at arbitrary positions regardless of wall thickness. This fact is extremely important for process simplification, since it results in shortening of the set-up operation and allows the elimination of the weld line tracking function.

3.2.2 Detectability of reference standard artificial flaw

Using steel pipes having an OD of 168.3 mm and various wall thickness as specimens, an investigation was made of the detectability of reference standard artificial flaws stipulated in the API standard and JIS using the multiprobe method. As an example of the results, the detectability of a 3.2 mmϕ drilled hole is shown in **Fig. 9**. The abscissa represents the wall thickness of the specimen, and the ordinate represents the echo height from a 3.2 mmϕ drilled hole. The figure indicates the mean value of echo heights and the fluctuation width of echo heights when the probe distance is 40 to 50 mm. The echo heights from the 3.2 mmϕ drilled hole show a virtually constant value regardless of the wall thickness of the specimen. The reason for this is as follows: In the conventional angle beam technique, the beam paths which produce varying peak echoes in accordance with the wall thickness differ greatly, making it impossible to ignore distance attenuation, while in the multiprobe method, echo height shows no peak phenomenon, and accurate values can be obtained using a single fixed beam path regardless of wall thickness. In the multiprobe method, it is possible to assume, based on the beam characteristics of the method, that the 3.2 mmϕ drilled hole is a horizontal-hole reflection of infinite length, and therefore, it is considered that detectability is uniform and does not vary with wall thickness.

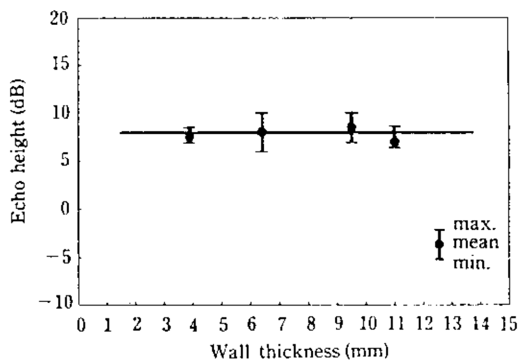


Fig. 9 Relationship between wall thickness and echo height from 1/8-in. drilled hole

Consequently, when the multiprobe method is used, it is possible to standardize the sensitivity of the ultrasonic inspection system without reference to wall thickness, eliminating the need for sensitivity calibration when the size set-up is changed.

3.3 Practical Application Techniques

A multiprobe weld flaw monitor was installed on-line immediately after the welding station, as shown in **Fig. 10**, with the aim of "building" quality into the manufactured product. Because the multiprobe weld flaw monitor is installed between the welder and an annealer, the service environment is extremely severe, and the following practical measures were necessary to ensure reliable performance.

3.3.1 Development of multiprobe assembly

Because of its service environment, the multiprobe assembly requires (1) heat resistance, (2) waterproofness, (3) electrical insulation, and (4) wear resistance. In particular, the acoustic wedge, which is critical element in the angle beam probe, must satisfy these four conditions. In the past, acrylic resin (methyl methacrylate polymer) was frequently used for the acoustic wedge of the angle beam probe, but this material posed problems of heat resistance and acoustic stability under changing temperature conditions. The authors investigated various raw materials including such new raw materials as engineering plastics, and adopted polyimide resin (a polycondensation-type nitrogen-bearing heat-resistance resin), which has excellent acoustic permeability and a high temperature resistance of 390°C, for the acoustic wedge of the multiprobe device. The polyimide resin is equal or superior to acrylic resin not only in heat resistance but also in waterproofness, insulation, and wear resistance, and also excels in temperature-related acoustic stability and provides good machinability.

To further improve the wear resistance of the multi-

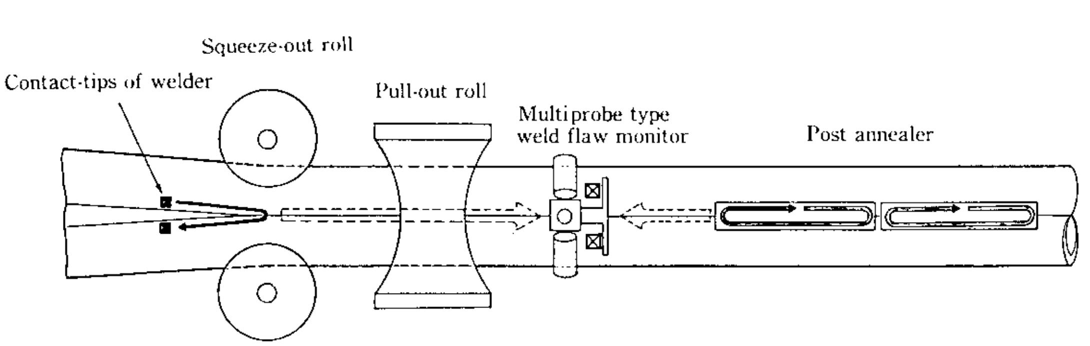


Fig. 10 Layout of multiprobe type weld flaw monitor

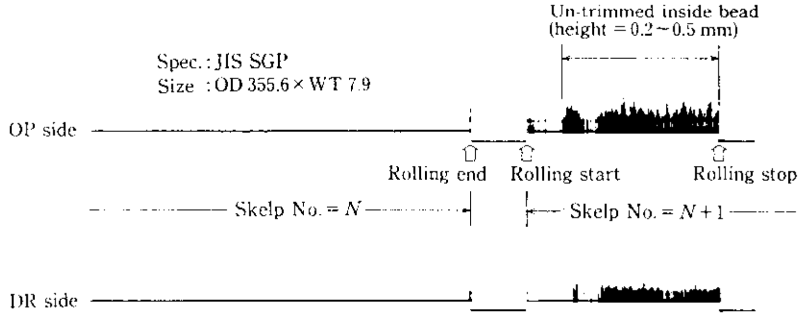


Fig. 11 An example of detecting chart

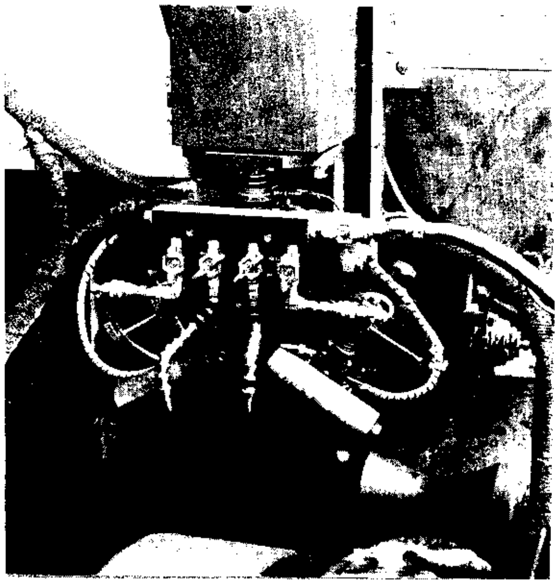


Photo 2 Appearance of multiprobe type weld flaw monitor

probe assembly, cemented carbide tips, which are made of a wear-resistant material, are used for the the front and rear shoes.

Photo 2 shows the external appearance of the multiprobe weld flaw monitor. The unit is designed to be of very compact size, with a line-direction lenglth of only about 250 mm, in spite of the fact that the mechanical parts include an elevating mechanism and guide rolls.

3.3.2 Noise countermeasures

Since the multiprobe weld flaw monitor is installed between a high-frequency, high-power welder and an annealer, noise was an obvious problem for flaw monitor operation. The various anti-noise measures shown below were taken.

(1) Complete electrical insulation of the multiprobe assembly
(2) Grounding based on noise theory
(3) Upgrading of transmission power (by changing damping material of probe)

These noise measure have sharply reduced the effect of noise. A typical on-line flaw-detection chart is shown in **Fig. 11**, and indicates the detection at a high SN ratio of an untrimmed inside bead 0.2 to 0.5 mm in height.

4 Conclusions

A multiprobe method was conceived for the inspection of ERW pipe welds, based on a new concept. An experimental comparison of the performance of this method and the conventional ultrasonic inspection method confirmed that both methods have the same detectability. Impediments to the automation of seam UT in the past, namely, the problems of shortening the set-up when sizes are changed, the necessity of calibration using test pieces, the need for accurate seam tracking, and mechanism operation problems, have all been eliminated with the new multiprobe method. Consequently, complete automation of seam UT has been achieved.

Since the multiprobe method allow simplification of the ultrasonic inspection system, both in terms of the mechanism and signal processing, the reliability of flaw detection has been greatly improved. Further, the equipment cost of the new ultrasonic inspection system has been significantly lowered, to about 1/4 that of conventional techniques. Thus the multiprobe method has become a powerful tool for the promotion of FA in the ERW pipe manufacturing line.

References

1) K. Konishi, T. Tsukui, H. Seino, S. Kawabata, Y. Enomoto, and M. Ida: *NKK Technical Report*, 102(1984), 33-42
2) M. Ataka, Y. Watanabe, H. Mori, N. Suzuki, Z. Chano, and H. Murayama: *Seitetsu Kenkyu*, 328(1988), 1-8
3) The Iron and Steel Institute of Japan: "Yousetu Koukan no Choonpa Tansyo (Ultrasonic Testing of ERW Steel Pipe)," (1988), 71
4) E. Asano, H. Baba, S. Uemura, and H. Kondo: *Kawasaki Steel Technical Report*, 4(1981), 116
5) H. Oide, M. Aratama, H. Kondo, K. Ohashi, A. Hiwasa, and T. Senba: *Kawasaki Steel Giho*, **18**(1986)2, 186
6) Republic Steel Corp.: Jpn. Kokai 57-500 439
7) M. Aratama, T. Okumura, and H. Kondo: *Current Advances in Materials and Processes*, **2**(1989), 1450