Abridged version

KAWASAKI STEEL TECHNICAL REPORT
No.16 (June 1987)

Automatic Seam Tracing System for ERW Pipe Mill

Fumiaki Ode, Mikio Aratama, Hiroaki Kondo, Kanehiro Ohashi, Atsushi Hiwasa, Takashi Senba

Synopsis :
Kawasaki Steel has developed two types of new equipment to detect and trace the weld-seam of ERW on pipe, and installed them at the 26 inch ERW pipe mill of its Chita Works. In most ERW pipe mills, a longitudinal welded portion is submitted to the seam-annealing process and non-destructive inspection, and therefore, detection and tracing of the exact weld-seam position at these processes are indispensable. The newly developed systems can detect and trace seam positions automatically and contribute to good quality of welded portions. Principle and actual application of these weld-seam detectors - one type called the "absolute seam position detecting method" and the other the "relative seam position detecting method" - are described in this paper.

The body can be viewed from the next page.

Automatic Seam Tracing System for ERW Pipe Mill*


Fumiaki Ode
Staff Deputy Manager, Equipment & Engineering Sec., Chita Works


Mikio Aratama
Staff Assistant Manager, Equipment & Engineering Sec., Chita Works


Hiroaki Kondo
Equipment & Engineering Sec., Chita Works


Kanehiro Ohashi
Manager, Small Welded Pipe Sec., Manufacturing Dept., Chita Works


Atsushi Hiwasa
Electro-Magnetic & Optical Product Engineering Sec., Ultrasonic and Specialty Electronics Dept., Kamakura Works, Mitsubishi Electric Corp.


Takashi Senba
Electro-Magnetic & Optical Product Engineering Sec., Ultrasonics and Specialty Electronics Dept., Kamakura Works, Mitsubishi Electric Corp.

Synopsis:

Kawasaki Steel has developed two types of new equipment to detect and trace the weld-seam of ERW on pipe, and installed them at the 26 inch ERW pipe mill of its Chita Works. In most ERW pipe mills, a longitudinal welded portion is submitted to the seam-annealing process and non-destructive inspection, and therefore, detection and tracing of the exact weld-seam position at these processes are indispensable. The newly developed systems can detect and trace seam positions automatically and contribute to good quality of welded portions. Principle and actual application of these weld-seam detectors—one type called the "absolute seam position detecting method" and the other the "relative seam position detecting method"—are described in this paper.

1 Introduction

The continuous manufacture of ERW pipe involves bending and forming steel strip with forming rolls, then welding the formed strip after melting the joint area by high frequency induction heating or high frequency conduction heating. Immediately thereafter follows a series of processes such as cutting and removing of beads which have been melted and discharged, non-destructive inspection of the weld, and heat treatment of the seam. An outline of the ERW pipe manufacturing process is shown in **Fig. 1**. The weld portion immediately after welding has a different heat history and forming circumstances than those of the base material portion, and it also varies in metal structure. Therefore, non-destructive flaw detection of the weld is necessary, and the metal structure must be improved by heat treatment. Particularly in recent years, ERW pipe is used in arctic areas and high strength is required; as a result, the seam portion must possess the same quality as the base portion.

Precise flaw detection of the seam is applied to the welded joint and the deformed portion of the base material near the joint over the entire length of the steel pipe by a ultrasonic flaw detector. This detector is capable of discriminating the location of flaws, but, for this purpose, it is necessary that the seam be traced precisely. In other words, the accuracy of seam tracing directly affects the performance of the ultrasonic flaw detector.

The seam annealer is a device to selectively heat only the weld zone from the outside surface of the steel pipe by an induction heating system. Usually equipped with plural heating coils arranged in the line direction, the seam annealer repeats regional heating to give an appropriate heat history to the weld.

For seam detection purposes, several systems have, in the past, been conceived as methods of determining the characteristic nature of the seam. Several such systems have been trial-manufactured and practically used, such as an eddy current method for detecting the seam, where structural differences cause electrical differences

* Originally published in *Kawasaki Steel Giho*, **18**(1986)2, pp. 186-191

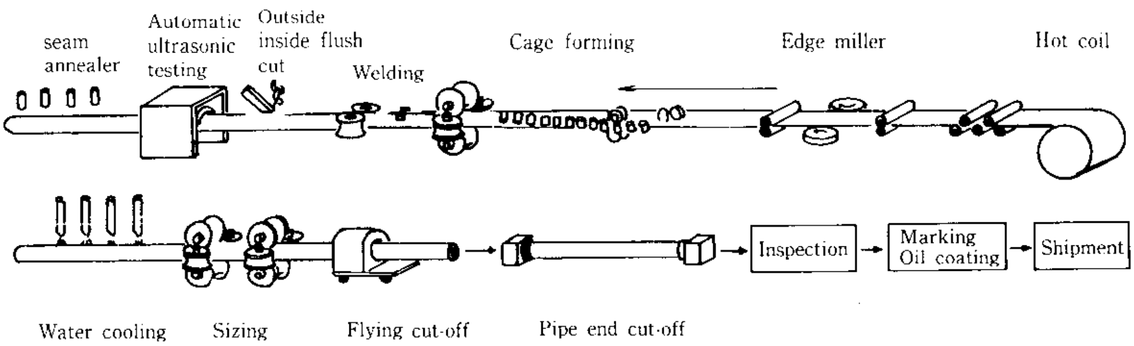

Fig. 1 Manufacturing process of ERW pipe

in characteristics, a method of detecting the effect of deformation in the immediate vicinity of the weld by electromagnetic ultrasonic waves based on the attenuation of sound waves, and a method of detecting the portion brightened by seam bead treatment. All, these methods, however, have shortcomings in accuracy or drawbacks in equipment size and weight.

As a method of isolating the features of the seam, the authors gave attention to the residual heat of the weld and developed a method of detecting the position of the seam on the basis of residual heat distribution.

2 ERW Pipe Seam Detection Method

2.1 Temperature Hysteresis of Welds

In manufacturing an ERW pipe, steel strip edges are regionally heated and melted by high frequency induction heating or high frequency conduction heating. The heating principle consists of the surface skin effect and proximity effect, and heating is accomplished by giving the same quantity of heating to both edge surfaces of the steel strip. Even after molten substances are discharged by pressure jointing immediately after melting and removed together with the swollen part of heat affected zone, uniform heat at both strip edges is maintained; the temperature distribution obtained is this symmetrical, in the pipe circumferential direction, with the weld line as a center.

A typical example of measured heat transfer conditions during the period from immediately before heating to post-welding is shown in **Fig. 2**. In this example, thermocouples were buried at the edge portion of the steel strip prior to welding, and measurements were made of temperature changes near the welded joint during the period from the start of heating to the completion of welding. The post-welding temperature at a location 1 mm from the welded joint rose sharply to a peak near the completion of welding, then cooled sharply. On the other hand, it was observed that the post-welding temperature 3 mm from the weld began to rise sharply around the time of pressure jointing. Further, the temperature 12 mm from the seam rose only slightly before pressure jointing and then rose after the completion of pressure jointing. In such welding-related heating, first the weld is rapidly heated, and then portions in the circumferential direction of the pipe are heated by heat transfer. It can be seen that even after a certain time following welding, residual heat is still present near the weld. It is characteristic of this heat distribution that the temperature is highest at the weld and drops gradually in the circumferential direction with distance from the weld. Although these measurements are concerned with the wall-thickness near-center area, it may reasonably presumed that outside surface temperature also displays symmetry around the weld line.

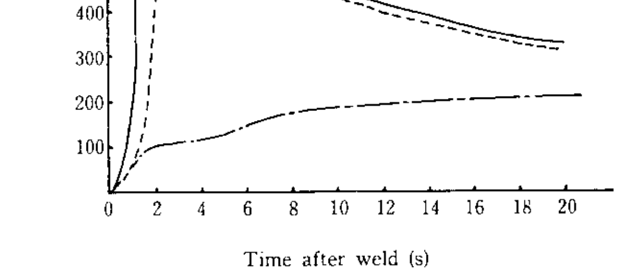

Fig. 2 Temperature of weld portion

2.2 Post-welding Outside Surface Temperature Distribution

The portion near the weld is subjected to an abrupt heating from room temperature to 1 500 to 1 600°C,

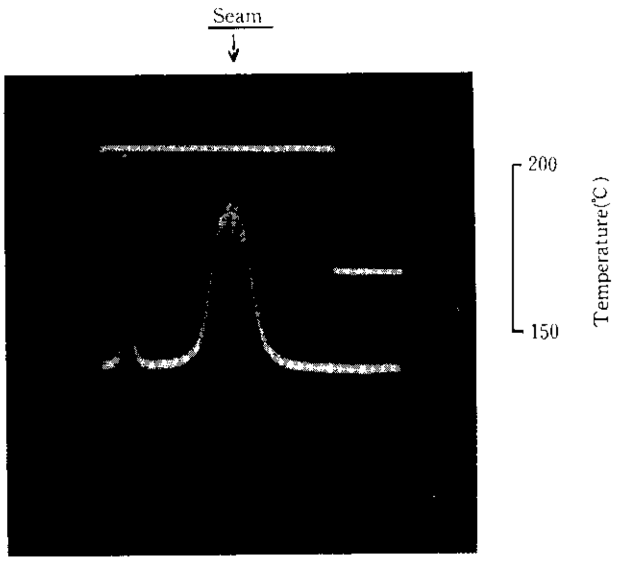

Photo 1 Temperature distribution

which is near the material melting point. After heating ends, the temperature drops suddenly. Although these are center area measurements, the same seems applicable to the outside surface temperature, but when the temperature of this portion was actually measured with a radiation pyrometer, it was found that abnormal values appeared when the following outside surface conditions obtained:

(1) The molten metal is discharged outward and beads are formed at both the outside and inside of the pipe. These molten beads are cut on the inside and outside surfaces in such a way that arc shapes form on the surface. The cut width is about 15 mm.
(2) The base metal portion is covered with oxides; its emissivity is about 0.8, while that at the cut portions is about 0.2.

This surface condition is shown in **Photo 1**. The bead-cut portion shows a high true temperature, but its emissivity is low and, further, its condition is unstable and its temperature indicates erratic. Portions other than the cut area, on the other hand, show a temperature distribution symmetrical to the center line and gentle temperature gradients. The radiation pyrometer, in general, detects the total radiation energy shown in Eq. (1)[1].

$$E = \varepsilon \sigma T^4 \cdots\cdots\cdots\cdots (1)$$

where E: Total radiation energy (W/cm^2)
ε: Emissivity
σ: Stefan-Bolzmann's constant (6.573×10^{-12} $W/cm^2 \cdot deg^4$)
T: Temperature (K)

The total radiation energy of a substance is determined by its temperature and emissivity, and is proportional, in particular, to emissivity. Therefore, the measured value by the radiation pyrometer is affected not only by temperature but also by fluctuations in emissivity, and when emissivity is minimal, the temperature indicated by the radiation pyrometer is lower than the true temperature. Therefore, a comparison of the true temperatures of the base metal and cut-bead portion is difficult using the apparent temperature indication given by the radiation pyrometer. Even if the residual heat from welding is diffused by heat transfer in a symmetrical temperature distribution with the seam line as a center, the temperature indicated by the radiation pyrometer conversely indicates a lower value at the center of weld bead owing to the effect of emissivity.

As a means of measuring this residual heat using the radiation pyrometer, one method equalizes emissivity by coating the pipe surface with a black-body paint which eliminates the effect of emissivity, but this method involves an additional coating process and increases operating costs, which are obvious disadvantages.

The authors have developed a seam detection method which is unaffected by emissivity and utilizes the symmetric nature of residual heat.

2.3 Absolute Seam Position Detection Method

From the fact that welding residual heat shows a symmetrical temperature distribution with the seam line as its center, the authors have developed a seam detector, the operation method of which is shown in **Fig. 3**. In this system, in order to avoid problems caused by erratic temperature distribution in the center portion, the center position of a location in a temperature distribution obtained by "slicing" actual values to a temperature level lower than the apparent indication temperature is determined; this is taken to be the seamline. The reference heat source is also fixed securely in the scanning visual field of the scanning pyrometer, and the absolute posi-

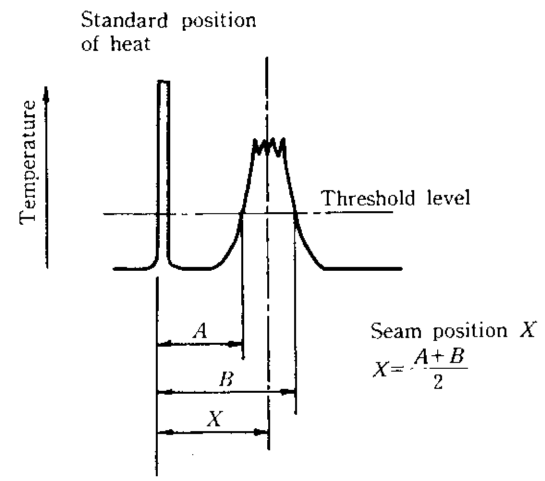

Fig. 3 Principle of absolute seam position measurement

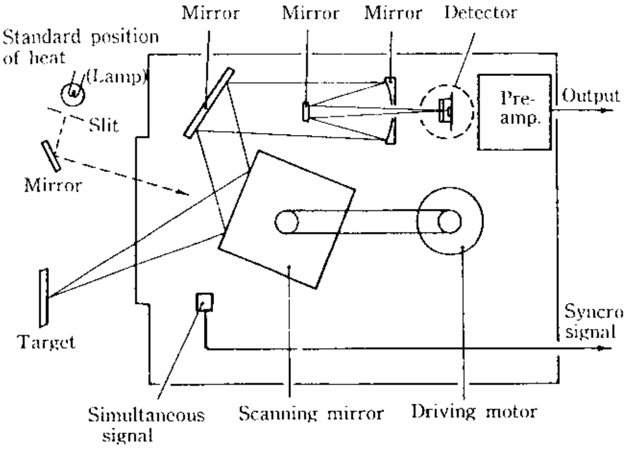

Fig. 4 Mechanism of absolute seam position measurement

Table 1 Absolute seam position detecting system

Item	Specifications
Temperature range	500°C max.
Sensitivity of temp.	4°C (at 150°C)
Range of measuring position	250 mm
Sensitivity of position	0.25 mm
Detector type	HgCdTe
Scanning method	Rotating mirror
Scanning cycle	1/30 s
Distance of measurement	500 mm

tion of the seam location can be measured by measuring the distance from the reference heat source.

The internal constitution of the seam detector is shown in **Fig. 4**. The spot pyrometer scans an instant visual field over the steel pipe surface by means of a rotary mirror and measures the temperature pattern near the weld linearly. The infrared detector employs an HgCdTe element of the electronic cooling type to measure low temperatures. Details of the seam detector are shown in **Table 1**.

The advantage of this system is that the seam position can be defined as a distance from the reference position of the heat source; this system is effective when seam position signals are used with plural heating coils as position setting signals for the seam annealer, etc. This system, however, has, as a disadvantage, its relatively large size.

2.4 Relative Seam Position Detecting Method[2,3]

The principle of the relative seam position detection method is shown in **Fig. 5**. The method is a combination of an infrared-ray system and visual light system. The

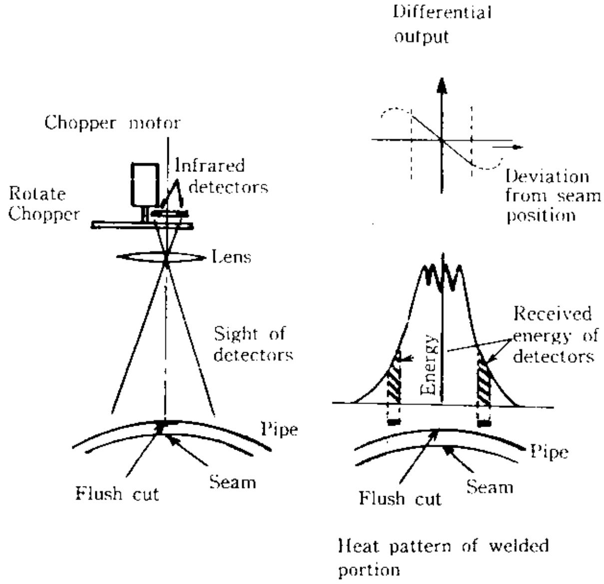

Fig. 5 Principle of relative seam position detecting method

infrared-ray system utilizes the symmetrical nature of the infrared radiation distribution, excluding the bead-cut portion; the seam position is determined by the position where infrared energy values received by a pair of infrared sensors become equal, as shown in the figure. When the centers of the two infrared sensors and the seam coincide, the infrared energy values become equal, and the differential output of the two infrared sensors is zero. If the center of the two infrared sensors deviates from the seam, a differential output of plus or minus value will be obtained. Therefore, if the sensor positions are moved so that the differential output is zero, the sensor positions and the seam position will always be in correspondence, thereby making it possible to trace the seam position.

In the optical detection system, two sensors are similarly incorporated. Light is reflected off the bright portion of the bead-cut portion, and the center of the bead-cut portion is determined from the differential output of the reflections.

The constitution of the relative seam position detection system is shown in **Fig. 6**. The detector in this system is smaller and lighter than that in the rotary mirror system, and a seam tracing mechanism, which combines this detector and a servo mechanism, can easily be formed. In the optical detection portion, two elements are incorporated, and in the infrared system, two symmetrical elements, out of 16 elements, are used.

A chopping motor is used to extracted respective signals as AC outputs to improve the S/N ratio. The differential output characteristics of infrared seam

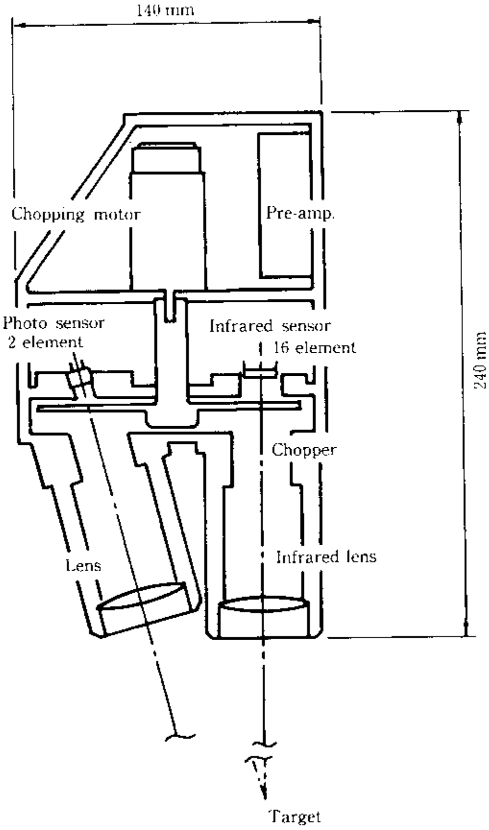

Fig. 6 Schematic of relative seam position detecting system

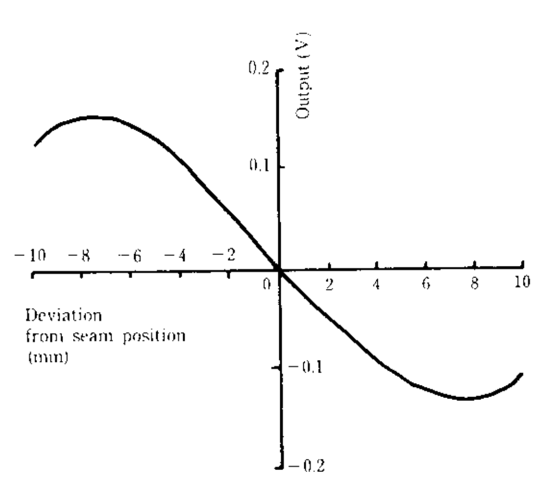

Fig. 8 Output by optical method of relative seam position detecting system

Table 2 Specifications of relative seam position detecting system

Item	Specification
Temperature range	150～700°C
Sensitivity of position	±0.7 mm
Response time	30 ms (90% rise time)
Output signal	DC 0～±5 V/0～±5 mm

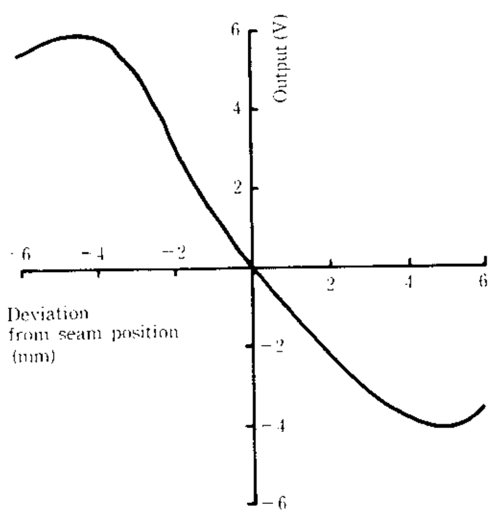

Fig. 7 Output by infrared method of relative seam position detecting system

detection are shown in **Fig. 7**, and the differential output characteristics of optical seam detection are shown in **Fig. 8**. Both characteristics become linear near the seam center. Specifications of the seam detector are shown in **Table 2**.

As mentioned above, the absolute seam position detection system can directly output the seam position and is advantageous for use with the seam annealer, in which a single detector is used for controlling several seam annealing devices which functions independently. But it is not suitable for equipment such as ultrasonic testing equipment, which must be light in weight. On the other hand, the relative seam position detection system is smaller and lighter, and is advantageous when the detector is incorporated into ultrasonic test equipment.

3 Seam Annealer Seam Tracing Control[4)]

An example of applying the seam detector to a 26″-mill seam annealer is shown in **Fig. 9**. The seam position detector used here is the absolute seam position detection system. A schematic is shown in **Fig. 10**. Through the use of a position setting mechanism which elevates the measuring device according to pipe outer diameter, the measurement distance between the measuring device and the outside surface of the pipe can be set to a

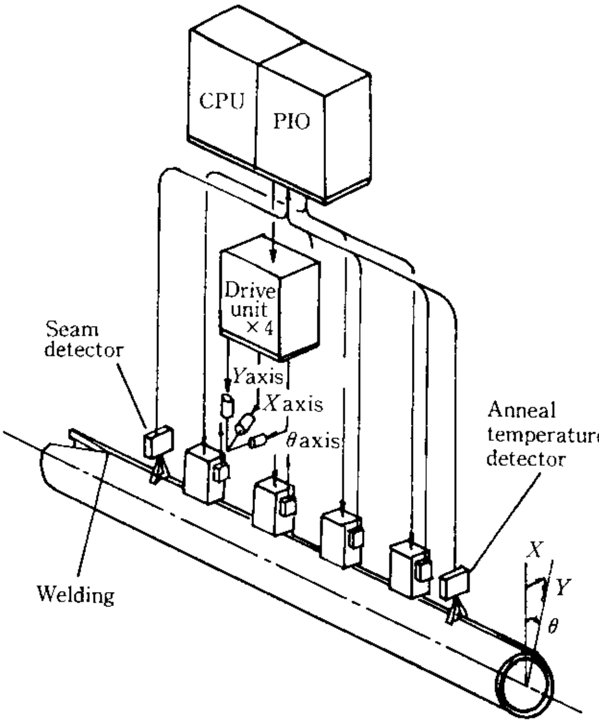

Fig. 9 Seam annealer control system using absolute seam position detector

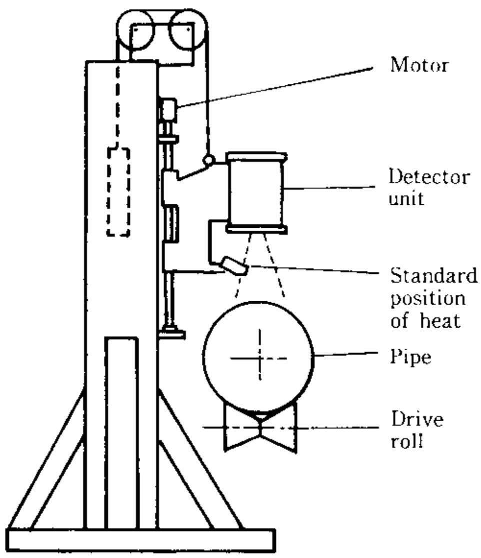

Fig. 10 Absolute seam position detecting system installed in 26″ ERW mill

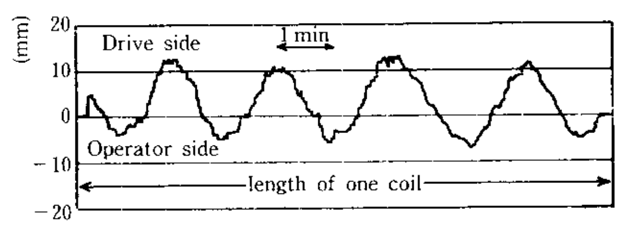

Fig. 11 Result of absolute seam position tracing at seam annealer (under worst case condition)

constant value (500 mm). Since the pyrometer is of a rotary scanning, this prevents changes in dimensional resolution with regard to the measured object caused by changes in distance. Further, because the detector elevates perpendicular to the pass line, and the reference heat source and detector are parts of a single unit, even if the outside diameter of pipe is changed, the detector will be situated at a constant angle at all times.

The seam annealer is composed of four induction coils and is fully-automatically controlled by computer. All functions of heat treatment for the seam at a correct and stabilized temperature have been automated; these include heating temperature control at heat treatment, gap control, for setting a constant distance between the heating coils and the pipe surface, and seam tracing control, for positioning the heating coils along the seam line. Among these control items, it is the role of seam tracing control to drive the four induction coils independently until they are positioned on the seam line. The induction coils can trace the arc locus of the pipe surface by triaxial driving in the three axes, X, Y, and θ, and can be positioned in an arc shape within a range of ± 50 mm for all outside diameters. The computer receives signals from the seam detector which has been installed at the inlet side of the annealer, calculates independently the positions of the four induction coils with respect to the pass line, and determines the positions of the coils. In making various calculations from the position of the seam with respect to the pass line, the seam detector of the absolute seam detection system is more advantageous.

An example of signals from the seam detector is shown in **Fig. 11**, which represents a case of worse pipe-making conditions, when the seam line is snaking widely. Since independent positioning is possible for the respective induction coils, a tracing accuracy of ± 1.5 mm can ordinarily be obtained.

4 Seam Tracing Control for Ultrasonic Test Equipment

The specifications of ultrasonic test equipment incorporating the relative seam position detecting system are shown in **Table 3**.

The system constitution of the ultrasonic test equipment is shown in **Fig. 12**. The seam detector detects the

Table 3 Specifications of ultrasonic testing system mounted in 26″ and 6″ ERW mill

Item	Specification	
Pipe size		
Outside dia.	267.4～660.4 mm	60.3～168.3 mm
Thickness	3.96～ 22.0 mm	1.2～ 11.5 mm
Seam twist of pipe	±20°	±20°
Pipe speed	60 m/min max	65 m/min max
Inspection area	±10～15 mm (Seam area)	
Trace speed	6°/s	
Trace angle	±20°	
Tolerance	±1.5 mm	

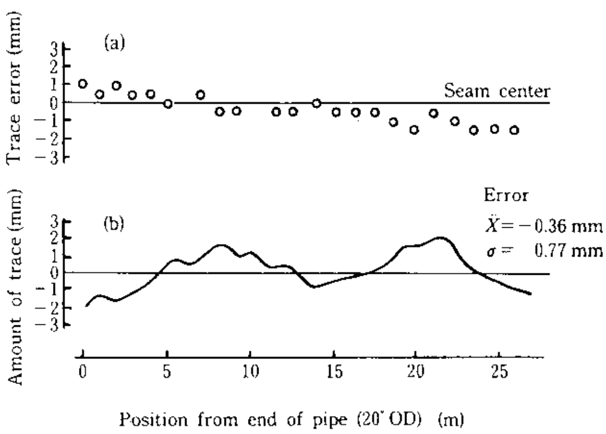

Fig. 13 Test data of relative seam position tracer mounted on ultrasonic testing equipment

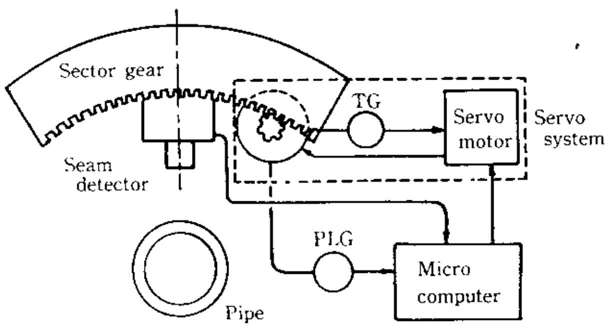

Fig. 12 Relative seam position tracer mounted on ultrasonic testing equipment

deviation of the sensor head center from the seam position, and impresses a voltage that corresponds to the deviation, as a signal concerning position, to the servo-amplifier. This amplifier is directly coupled to the tachometer generator, and impresses the signal concerning rotational speed to the servo-amplifier, thereby forming a servo-loop and causing the sensor head to trace the seam position smoothly. The probe of the ultrasonic test equipment is housed in a probe retention mechanism and installed so that the probe retention mechanism center will be aligned with the sensor center, thus allowing the probe also to trace the seam correctly.

4.1 Seam Tracing Performance

The following shows the overall seam tracing performance when the seam position detector is mounted on the automatic ultrasonic tester and the probe retention mechanism is tracinge the seam. In this case, a mark which corresponds to the position of the probe retention mechanism is affixed to the surface of pipe being carried by transportation facilities. The distance between the mark and the seam is actually measured at a downstream stage. This measured result is taken to be the overall seam tracing performance of the seam detector.

4.1.1 Automatic tracing test data

An example of measuring the overall performance of the seam position detector at the time of manufacturing an ERW pipe of 20″ outside diameter at the ERW pipe of 26″ manufacturing line is shown in **Fig. 13**. In this figure, (a) shows the fluctuation of seam position with respect to the center of the probe retention mechanism. The abscissa corresponds to the lengthwise direction of the ERW pipe. Figure 13 (b) shows the movement of the probe retention mechanism at this time. Figure 13 clearly indicates that fluctuation of seam position with respect to the center of the probe retention mechanism is converging on the vicinity of zero. The fluctuation width is within ±1.5 mm, even considering allowance made for measurement errors. The degree of movement of the probe retention mechanism at this time is about ±2 mm from Fig. 13 (b).

4.1.2 Effect of automatic tracing control

A summary of the results of automatic tracing tests conducted using various diameters is shown in **Fig. 14**. The test results for pipe having an outside diameter of 16″ or above were obtained by ultrasonic testing equipment on the 26″ mill, and those for pipe having an outside diameter of less than 16″, by mounting the type of ultrasonic testing equipment on the 6″ mill. The ordinate in the figure shows the fluctuation ranges for various sizes, denoted by $\pm\sigma$. When no automatic tracing control is effected, tracing accuracy fluctuates widely, but with automatic tracing control, the fluctuation range is significantly reduced. In the figure, further, the permissible range of ±1.5 mm, determined from flaw detection conditions, is shown by dotted lines.

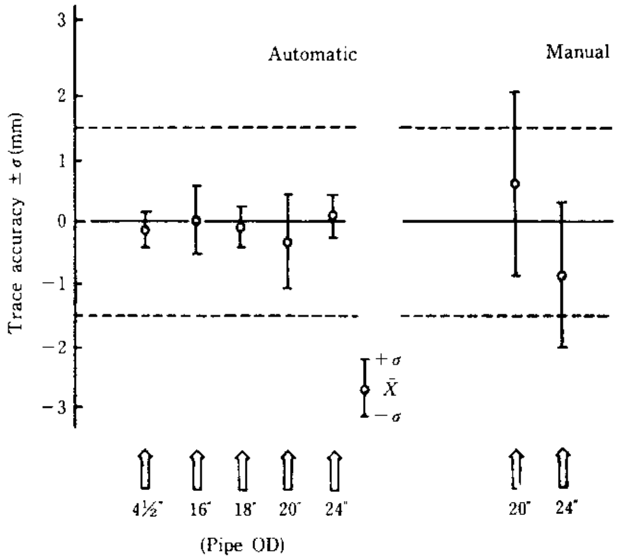

Fig. 14 Effect of automatic relative seam position tracer

5 Conclusions

For ERW pipe manufacturing facilities, the authors have developed and practically applied a seam position detector, utilizing the residual heat of welding and employing either an absolute seam position detection system or relative seam position detection system. To fully utilize the features of the respective systems, the absolute seam position detector is incorporated into the fully-automatic system of the seam annealer. In the automatic ultrasonic tester, the lightweight relative seam position detection system is used in combination with a servo system, thereby realizing seam tracing. With the seam annealer, an accuracy of ±1.5 mm is ordinarily obtained, thereby contributing to the reliable low-temperature toughness of the steel pipe manufactured. With the ultrasonic testing equipment, a tracing accuracy of ±1.5 mm is obtained, thereby guaranteeing the overall performance of the unit.

Welding residual heat temperatures in steel industry processes are comparatively low, and lie in a region where measurement is difficult. However, by using a non-contact temperature measurement technique and an analysis technique for the special features of welding residual heat patterns, it has been possible to develop a practical seam position detector. In the future, when delicate fluctuations in the process are to be detected, the pattern temperature measuring technique discussed here will be actively used.

The seam position detector for ultrasonic testing equipment was jointly developed with Mitsubishi Electric Corp., and sincere appreciation is hereby extended to the staff of Mitsubishi Electric Corp. for their kind assistance and valuable advice in the course of the present development project.

References

1) SICE: Ondo Keisoku (Temperature Measurement)" (1981), 178
2) K. Ohashi, F. Ode, H. Kondo, T. Semba, K. Honda, H. Naito, and A. Hiwasa: "A Seam-Position Detector for Electrtric-Resistance Welded Tubes," *Mitubishi Denki Giho,* **59**(1985)8, 42~45
3) K. Ohashi, Y. Funyu, H. Kondo, M. Aratama, T. Senba, and A. Hiwasa: *Tetsu-to-Hagané,* **71**(1985)5, S407
4) T. Tamura, Y. Hosokawa, Y. Yoshimoto, F. Ode, M. Kurosaki, and I. Sugimoto: *Kawasaki Steel Giho,* **11**(1979)3, 143