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Nondestructive Inspection System for Tubular Products at Chita Works

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Synopsis :
Kawasaki Steel Corporation Chita Works is manufacturing a variety of tubular products of different types and size including small and medium diameter seamless tubes, small and medium diameter electric resistance welded pipe, spirally welded pipe and continuous butt welded pipe. The NDI system is described of all these tubular products, with emphasis on equipment and control, including training and qualification for inspectors as well as some innovative designs developed and installed recently.

The body can be viewed from the next page.

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Nondestructive Inspection System for Tubular Products at Chita Works*

Eiichi ASANO** Hitoshi BABA** Shigenori UEMURA**
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Kawasaki Steel Corporation Chita Works is manufacturing a variety of tubular products of different types and sizes including small and medium diameter seamless tubes, small and medium diameter electric resistance welded pipe, spirally welded pipe and continuous butt welded pipe.

The NDI system is described of all these tubular products, with emphasis on equipment and control, including training and qualification for inspectors as well as some innovative designs developed and installed recently.

1 Introduction

Chita Works manufactures tubular products of various types and sizes and has the pipe-making facilities of the world's first class both in terms of quality and quantity for a single plant. Further, its expansion project is currently under way.

Every piece of product manufactured at Chita Works is subjected to various strict quality control and quality assurance measures. The most important point in the quality assurance of pipe is to gurantee that each pipe is free of injurious flaws in its total length, and in order to ensure this, NDI is thoroughly employed. Particularly, oil country tubular goods (OCTG) for petroleum and natural gas and line pipes are recently used at an increasing rate in cold regions, under the sea or under such adverse conditions as high pressure or sour gas. Pipes used at power and chemical plants are also required to possess high quality as these plants become larger in size and capable of higher performance.

Hence, if even one single piece of the entire products delivered should develop an injurious flaw, it would lead to a serious accident, and therefore, existence of even a single defective pipe is impermissible. For this reason, total inspection is required, and efficient inspection must be performed by well-trained operators using high precision equipment. The role played by the automatic NDI is getting increasingly important.

Since injurious flaws of steel pipe vary in types and degrees depending upon the kind, manufacturing method and application of the pipe, NDI methods and equipment employed are only those suitable for each occasion. In the following, NDI systems used and main systems recently developed and installed at Chita Works are reviewed, and the control system of NDI, and training and qualification of inspectors are reported.

The types and dimensions of tubular products manufactured at Chita Works are shown at the end of this journal as a data sheet.

2 Medium Diameter Seamless Tubes

2.1 Manufacturing and Inspection System and Its Features

Medium diameter seamless tubes are manufactured by the Mannessmann plug mill process. Major products include casing and line pipe. The manufacturing and inspection processes of these tubular products are shown in **Fig. 1**. Billets are rolled by the piercer, elongator, plug mill and reeler, pass through the reheating furnace and sizing mill and are formed into pipes of high precision. Some pipe products are directly quenched and then tempered. All these operations are automatically controlled by computer.

At the finishing process, various NDI systems are installed on-line and products are inspected in the state of uncropped condition. Namely, products are inspected piece by piece and along their entire length by the magnetic leakage flux testing system. Simul-

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** Chita Works

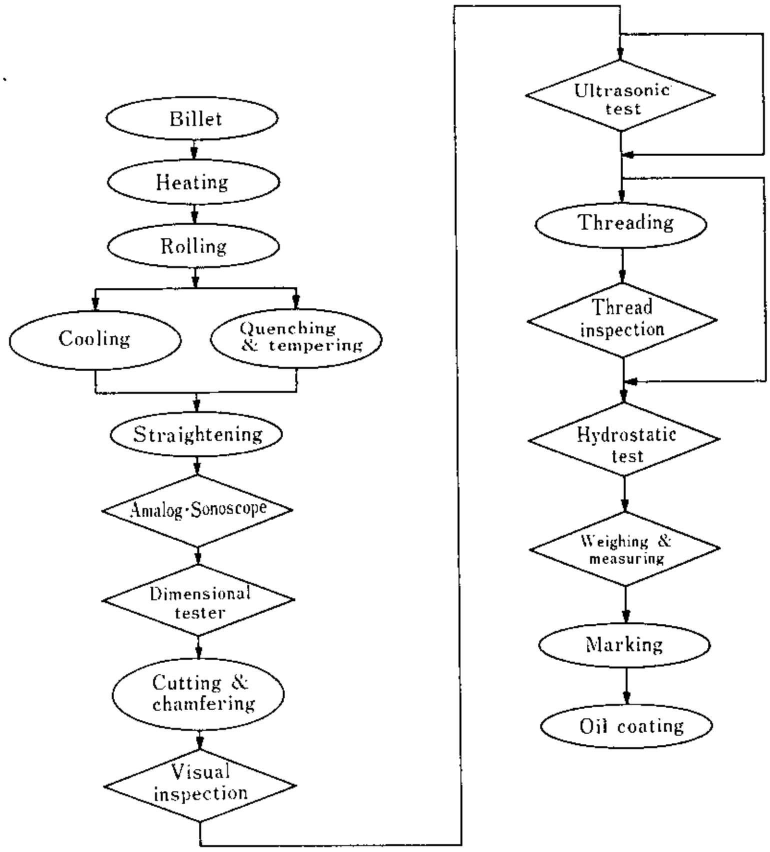


Fig. 1 Manufacturing process of medium diameter seamless tube

taneously, continuous measurement of the outside diameter and wall thickness is performed. The plant is provided with an on-line computer and piece-by-piece tracking is performed. The results of the NDI are also data-logged by the computer, and fed forward realtime to the next final inspection process.

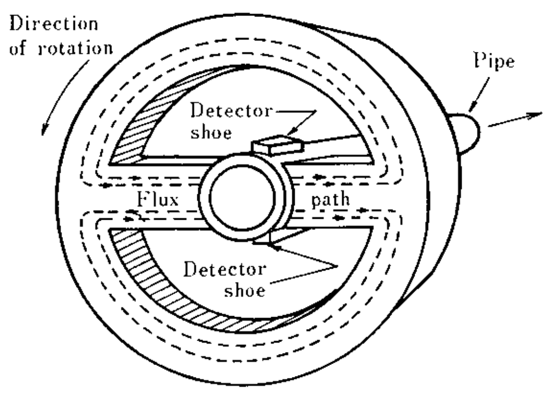
Besides the above, an automatic ultrasonic testing system is installed and double inspection of the magnetic leakage flux test and ultrasonic test is often performed, depending upon the grades and dimensions (particularly, wall thickness) of pipe.

2.2 NDI Equipment

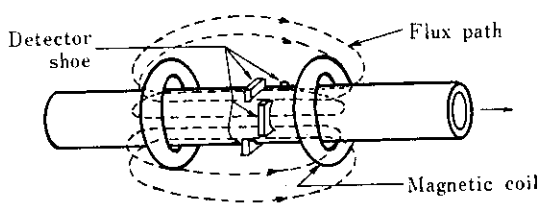
2.2.1 Amalog and Sonoscope systems*

This is an inspection system made by AMF. Tuboscope Inc., which utilizes the magnetic leakage flux testing method. It is capable of high flaw-detectability and fast inspection-speed. Principles of flaw detection by this equipment are shown in **Fig. 2**. The Amalog section can mainly detect longitudinal flaws, but is also capable of detecting short, pit-like flaws.

*Amalog and Sonoscope are trademarks of AMF. Tuboscope Inc.



Amalog magnetic circuit



Sonoscope magnetic circuit

Fig. 2 Schema of Amalog and Sonoscope units

The Sonoscope section mainly detects transverse flaws, but can thoroughly detect pit-like flaws like the Amalog section. Both Amalog and Sonoscope can perform magnetization by direct current and detect flaws on the inside and outside both, thereby covering the entire surface of the pipe to be inspected.

The following are improvements over the standard equipment, which are incorporated in the Amalog and Sonoscope units.

(1) The number of sensor channels is increased in the Amalog unit compared with the conventional equipment, and the number of revolutions of the rotary body is also increased, so that the inspection speed is raised to about 1.3 times as much as the conventional equipment.
(2) Marking is put on the outside close to flaws according to each large or small flaw on the inside or outside by markers located in 8 segments on the circumference of the pipe.
(3) The Amalog unit is provided with the off-line calibrator. It also incorporates an automatic size-changing device developed by Kawasaki Steel. The Sonoscope also has been modified into a quick-changing type to facilitate size changing. Through these measures, it is easier to change the sizes and to adjust the sensitivity of the Amalog and Sonoscope system, with time required for this changing operation reduced to about 1/3 that of the conventional standard equipment.
(4) In view of the heat treatment of pipe, a both-end gain-up function is provided which can detect flaws at both ends of the pipe with still higher sensitivity.

This system is now in the installation stage.

2.2.2 Continuous ultrasonic tester for outside diameter and wall thickness

The continuous ultrasonic thickness tester[1] developed by Kawasaki Steel has been further modified into an ultrasonic tester for outside diameter and wall thickness. With probes arranged at 8 positions on the circumference, every piece of pipe can be measured along the entire length, with measured values automatically recorded. Simultaneously, the maximum and minimum values, mean, and standard deviation of the outside diameter and wall thickness can be calculated per pipe and per lot. Then these measured values are compared with the respective control values for evaluation. A sketch of this equipment is given in **Fig. 3**. The system is also now in the installation stage.

2.2.3 Automatic ultrasonic testing system

This system is of the rotary probe type as shown in **Photo. 1** and is used for the quality assurance of higher-grade or thicker-walled pipe. The system was designed and produced jointly by Kawasaki Steel and Mitsubishi Electric Corporation and has the following many advantages compared with the conventional equipment[2-4]:

(1) Sensitivity setting is fully automated and the setting conditions and inspection results are stored and printed out by the computer. Inspection results can also be displayed in the developed diagram of the pipe and effectively utilized in quality control.
(2) Various modes shown in **Fig. 4** can be selected, thereby enabling the system to detect various types of flaws.
(3) The system is provided with a monitoring system not only for acoustic coupling between the pipe and probes, but also for any abnormalities.
(4) As shown in **Fig. 5**, the probe has been determined after investigation of its acoustic field. The probe is practically free of uneven sensitivity and has excellent detectability of small sized flaws.
(5) Non contact type rotary transformer is employed for transmitting signals between rotating and fixed

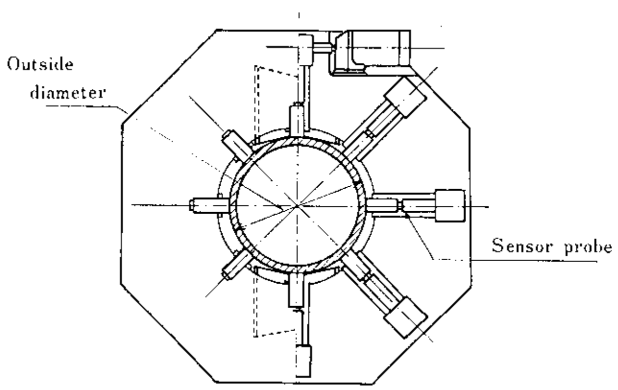


Fig. 3 Schema of continuous ultrasonic tester for outside diameter and wall thickness

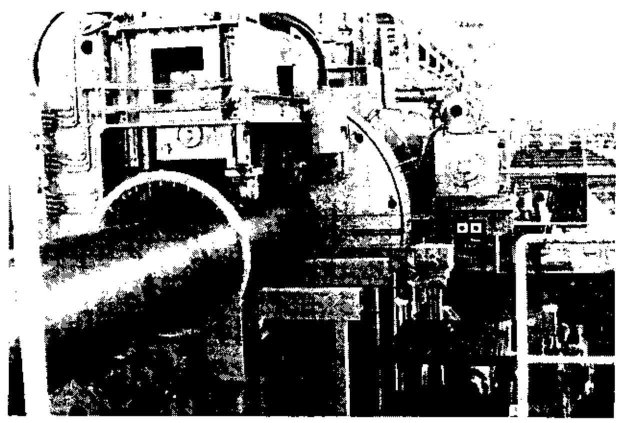


Photo. 1 Automatic ultrasonic testing system for medium diameter pipe

Mode	Head No.	Probe arrangement and direction of beam			
1	No. 1	+L	D		−L
	No. 2	+L	D		−L
	No. 3	+L	D		−L
	No. 4	+L	D		−L
2	No. 1	+L	+T	−T	
	No. 2		+T	−T	−L
	No. 3	+L	+T	−T	
	No. 4		+T	−T	−L
3	No. 1	+L			−L
	No. 2	+L			−L
	No. 3	+L			−L
	No. 4	+L			−L

L : Probe for longitudinal flaw
T : Probe for transverse flaw
D : Probe for laminar flaw
+ for L : Clock-wise direction
− for L : Counter-clock-wise direction
+ for T : Pipe travelling direction
− for T : Reverse to the above

Fig. 4 Three modes of UST probe usage

parts, thereby enabling flaw detection at a high S/N ratio and maintenance-free operation.

(6) Besides the above, many automatic operations and checking functions are provided, and simultaneously, improvement of reliability and reduction of time for size changing and for sensitivity adjustment have been achieved.

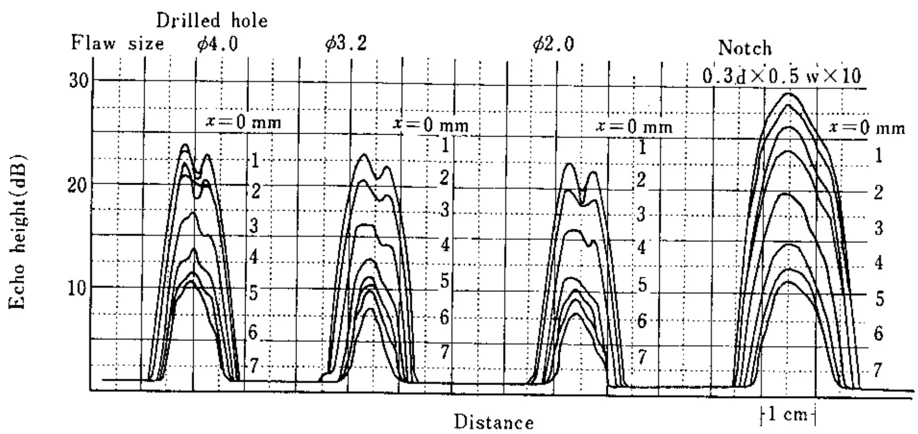
3 Small Diameter Seamless Tubes

3.1 Manufacturing and Inspection System and Its Features

Small diameter seamless tubes at Chita Works are manufactured by the Mannessmann mandrel mill process.

Its main products include pipe and tubes for various applications such as casing, tubing, drill pipe and line pipe for oil wells, carbon steel and alloy steel tubes for boilers and heat exchangers, tubes for high and low temperature services, and pipe for high pressure services and machine structural purposes. The remarkable feature is that so many types of tubular products are manufactured here, and various types of NDI systems are used according to these types of the products. **Fig. 6** shows the manufacturing and inspection process. Billets are rolled by the piercer and mandrel mill and, after passing through the reheating furnace, are made into pipe and tubes having specified outside diameters and wall thicknesses by the hot stretch reducer with high precision.

In the finishing process, on-line eddy current flaw detectors are installed to inspect all products along their entire length. An automatic ultrasonic flaw detector and a magnetic particle flaw detector are also



Test frequency : 5 MHz Skip : 1.0
Transducer size : 6 × 15 mm
Refraction angle : 38°
Thickness of test material : 10 mm

Fig. 5 Acoustic field characteristics of probe for longitudinal artificial flaws

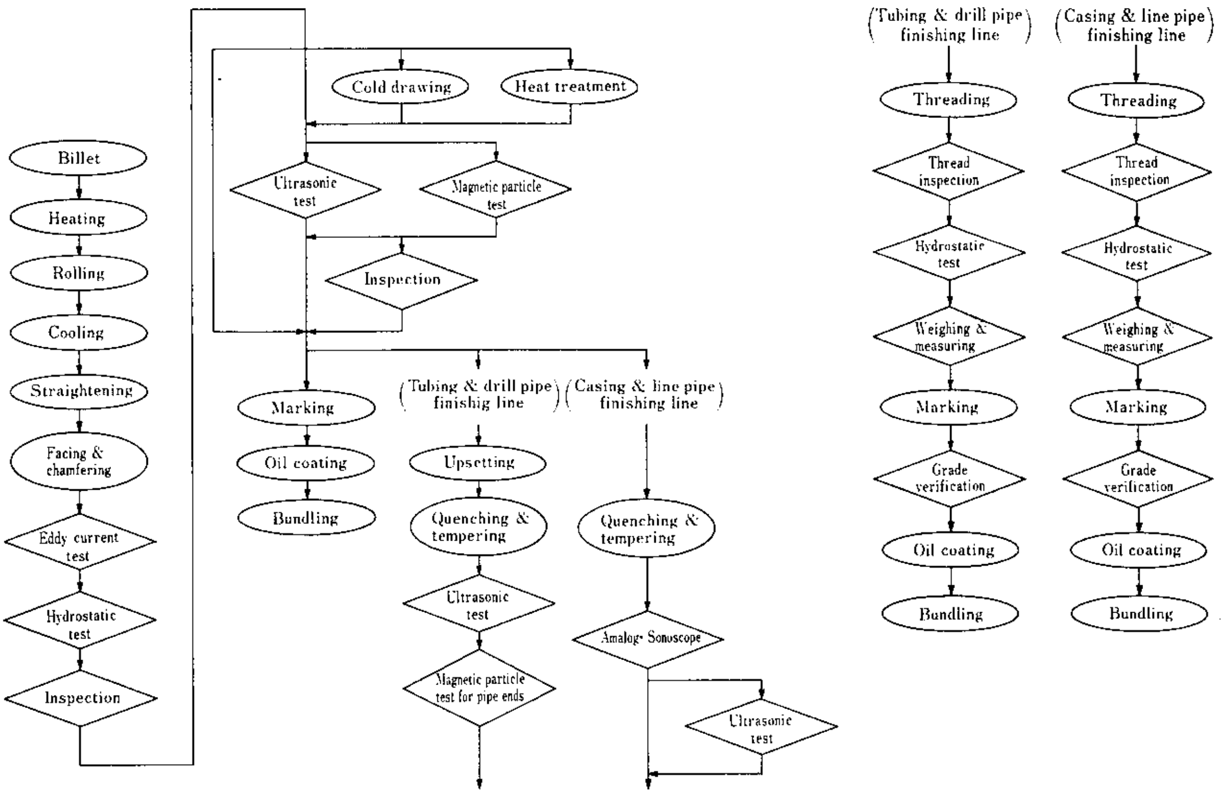


Fig. 6 Manufacturing process of small diameter seamless tube

installed to be used properly according to the types and applications of pipe and, together with the eddy current detector, performs double or triple inspections.

Further, two finishing lines for manufacture of OCTG are installed, where ultrasonic flaw detection is performed on tubing and drill pipe, magnetic particle flaw detection is applied to the upset portion, and inspection by Amalog and Sonoscope unit is employed for casing and line pipe. Since both finishing lines are quite long, a grade verification test is conducted just before the pipe is bundled.

3.2 NDI Systems

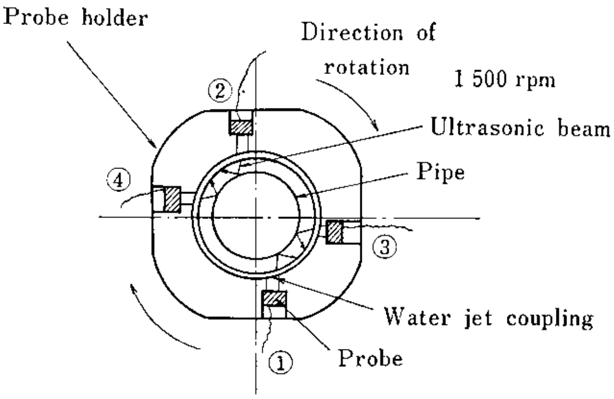
3.2.1 Eddy current flaw detector

This plant has two primary finishing lines, as mentioned above, both of them being provided with one eddy current detector each to perform total inspection. The flaw detection method used is the encircling coil type self-comparison technique. They employ electromagnetic induction and are capable of increasing the detecting speed. Combined with the highly rigid conveyor and the quick speed-accelerator designed by Kawasaki Steel, the flaw detector is now demonstrating high-speed flaw detection with high accuracy.

3.2.2 Automatic ultrasonic flaw detector

This detector is of the rotary probe type. It was introduced in 1971 and has since been operating smoothly. It was originally developed as RP4" by British Steel Corporation and modified for flaw detection on pipe having a diameter of up to $6^5/_8$". **Fig. 7** shows the arrangement of its probes and beam directions. Four probes are rotating around the pipe at a high speed of 1 500 rpm and, with the help of clockwise and counterclockwise beams, detect flaws in both directions with high efficiency. After its introduction, this detector was modified as follows by utilizing Kawasaki Steel's techniques:

(1) At a refraction angle of 40°, flaw detection was possible only for pipe of "(thickness/diameter)≦ 17%," and so the detector was modified so that a refraction angle smaller than 40° and mode transformation of ultrasonic beam could be used. As a result, flaw detection of all the pipe products manufactured at this plant became possible.
(2) In addition, the driver, pipe guide units, and recording systems were modified so that high-accuracy, high-speed-rotation flaw detection became possible.



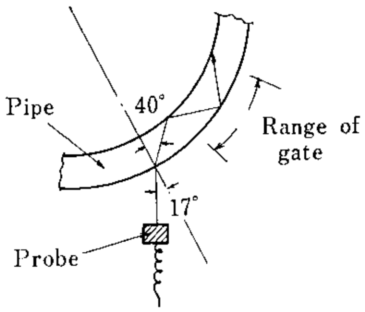


Fig. 7 Schema of automatic ultrasonic flaw detector for small diameter seamless tube

3.2.3 Magnetic particle flaw detector

The magnetic particle flaw detector uses magnetic particles for detecting magnetic leakage flux and has highly accurate flaw detecting capability; and therefore, it is employed for pipe which requires detection of shallow-flaws on the surface. As shown in **Fig. 8**, this detector applies the axial transmission magnetizing method to longitudinal flaws over the entire length of the pipe and uses the coil magnetizing method at pipe ends, thereby making it possible to detect flaws in the longitudinal and transverse directions at pipe ends. For magnetic particles, wet fluorescent magnetic particles are used, which can detect very shallow flaws under the ultraviolet light. The operations are automated, including bringing-in and -out of the pipe, magnetizing, application of magnetic particles, and demagnetizing, resulting in stabilized flaw detection.

3.2.4 Amalog and Sonoscope system

The Amalog and Sonoscope unit which is installed at the casing and line pipe finishing line detects flaws on high grade casings and line pipes that have been heat treated by Kawasaki Steel's unique quenching and tempering equipment of induction heating type. Principles and specifications of this Amalog and Sonoscope system are nearly the same as those of the Amalog and Sonoscope system for medium diameter seamless pipes described in Par. 2.2.1; except that the former's detection part is a unit having special specifications permitting the equipment to be used for both seamless and ERW pipe. The reason for this is that ERW pipe is also finished at the casing and line pipe finishing line. In the magnetic leakage flux flaw detection, the weld of the ERW pipe generates unique signals, and Amalog unit processes these signals and detects flaws on the weld with higher sensitivity than on the pipe body. This equipment also has a pipe-end gain-up function[5].

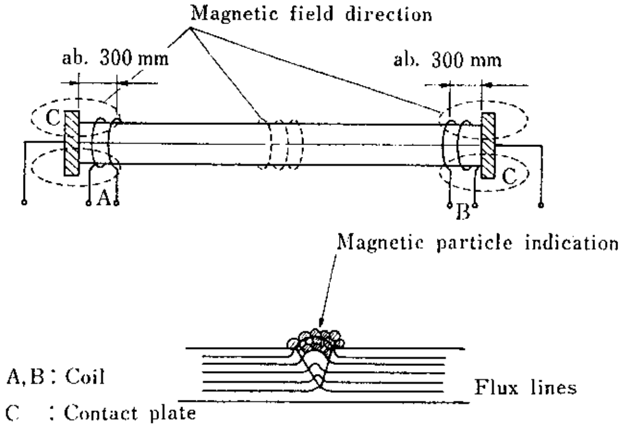


Fig. 8 Schema of magnetic particle flaw detector for seamless tube

3.2.5 Automatic ultrasonic testing system for tubing

At the tubing and drill pipe finishing line, ultrasonic flaw detection is performed over the total length and total surfaces of heat treated pipe except for its upset portion. For checking heat treatment flaws, this system can perform high accuracy, high efficiency flaw detection on the on-line basis in respect of both longitudinal and transverse flaws by using a total of 24 multi-probe channels. As shown in **Fig. 9**, probes are incorporated into 6 lever-shaped searching units,

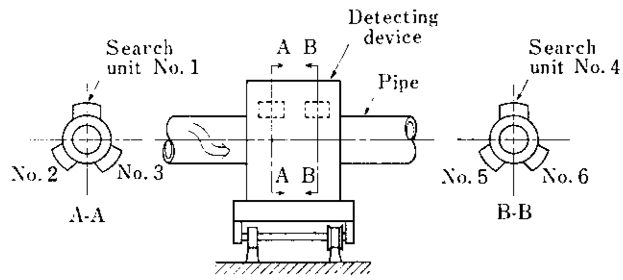


Fig. 9 Schema of ultrasonic testing system for tubing

and the pipe travels spirally through these detecting mechanisms. The 6 searching units perform flaw detection by maintaining contact with the pipe surface except at the upset portion. This testing system has the following special functions like the automatic ultrasonic testing system for medium diameter seamless pipes:

(1) Automatic sensitivity setting by computer
(2) Automatic printouts of test conditions and results by computer
(3) Acoustic coupling monitor
(4) Function of monitoring anomaly by the system itself

3.2.6 Magnetic particle flaw detector for pipe ends

This detector simultaneously detects longitudinal and transverse flaws on the inside and outside surfaces of upset pipe ends. For the magnetizing method, the duovec method combining the yoke method and the coil method is employed as shown in **Fig. 10**. Although the figure does not show it, the magnetizing device by the yoke and coil methods and the inspection liquid application device are so arranged that they can be inserted into the inside of the pipe, so that by a single operation, flaws in various directions both inside and outside the pipe can be simultaneously detected. This detector was developed through the joint efforts of Kawasaki Steel and Nippon Denji Sokki Co., Ltd., and features a special method of magnetizing the pipe interior. Even if the pipe is thick-walled, a high magnetic field can easily be induced over the inside and outside surfaces of the pipe, thereby ensuring high accuracy flaw detection. This detector also can be applied to flaw detection at pipe ends of non-upset pipe[6].

3.2.7 Grade verification tester

Chita Works performs, when required, grade verification tests using spark test or a portable spectrographic analyzer on tubes for boilers and heat exchangers and alloy steel pipe. At the OCTG finishing line which is a long production line, a grade verification device utilizing the electromagnetic method is installed just in front of the pipe bundling machine to perform grade verification. This system makes a comparison between the magnetic permeability of steel pipe and that of standard pipe. This tester is particularly useful for products whose hardness and microstructures vary owing to the difference in heat treatment conditions rather than in chemical composition. This tester is now in the installation stage.

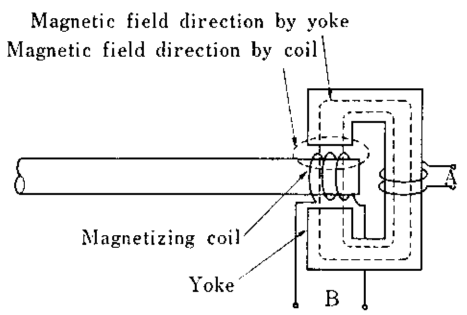


Fig. 10 Schema of magnetic particle flaw detector for pipe ends

4 Medium Diameter ERW Pipe

4.1 Manufacturing and Inspection System and Its Features

Chita Works incorporates 20″ and 26″ ERW pipe mills. The manufacturing and inspection processes of medium diameter ERW pipe mills vary slightly between the two mills. The manufacturing and inspection process for the 26″ mill is shown in **Fig. 11**. In both mills, improvement in the manufacturing tech-

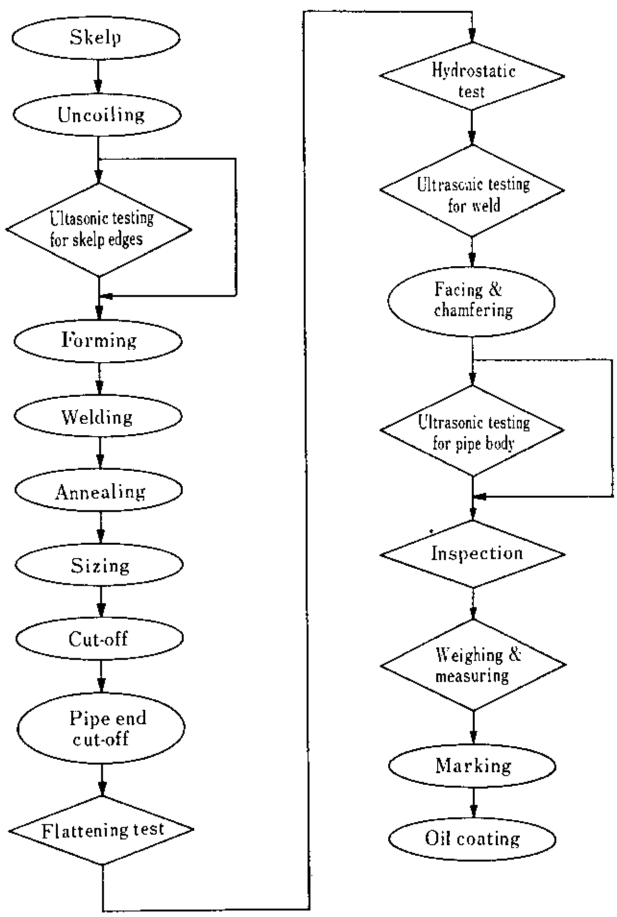


Fig. 11 Manufacturing process of medium diameter ERW pipe

niques of hot coils and ERW pipe and progress in nondestructive inspection techniques have made it possible to employ ERW pipe in a wide field, such as oil well casings (OCTG), high grade pipe, and pipe to be used under adverse conditions like sour gas, for which only seamless tubes and UO pipe were used in the past.

4.2 NDI Systems

4.2.1 Automatic ultrasonic flaw detector for skelp edges

Skelp edges are welded after forming and become welds. Since laminar flaws found at skelp edges are liable to cause welding flaws, skelp edges within the range of 25 mm at each edge for the total length of the skelp are subjected to flaw detection before forming.

This flaw detector:

(1) employs the ultrasonic through-transmission method, permitting stabilized flaw detection, even if slight deformation exists on skelp edges, and

(2) can satisfactorily detect even minor flaws by the ultrasonic through-transmission method, because 4 sets of probes are arranged at the 25 mm section on each side.

4.2.2 Automatic ultrasonic testing system for welds

These testers perform ultrasonic flaw detection over the entire length of weld zone and heat affected zones of ERW pipe and incorporate various functions to perform highly reliable flaw detection.

They are installed in the manufacturing process just after the hydrostatic testing machine. The probe holder is saddle-shaped, and the pipe advances by pushing it upwards and has its flaws detected over the entire length of the weld. As shown in **Fig. 12**, flaw detection is performed from both sides of the seam by 6 search units fitted to the probe holder. Each search unit also incorporates a probe for monitoring the acoustic coupling condition between the search unit and the pipe. When acoustic miscoupling occurs, the alarm, recording, and paint marking are performed and the pipe is sent to the reinspection table, thereby preventing flaw detection to be performed while the flaw detecting sensitivity is below the specified level.

Further, these systems are provided with functions such as a seam guiding device and distance amplitude compensation (DAC), for a high accuracy flaw detection.

Besides the flaw detecting system by the water gap coupling method, 20″ ERW pipe mill also has a system by the water jet coupling method. The latter system also has the same functions as mentioned above.

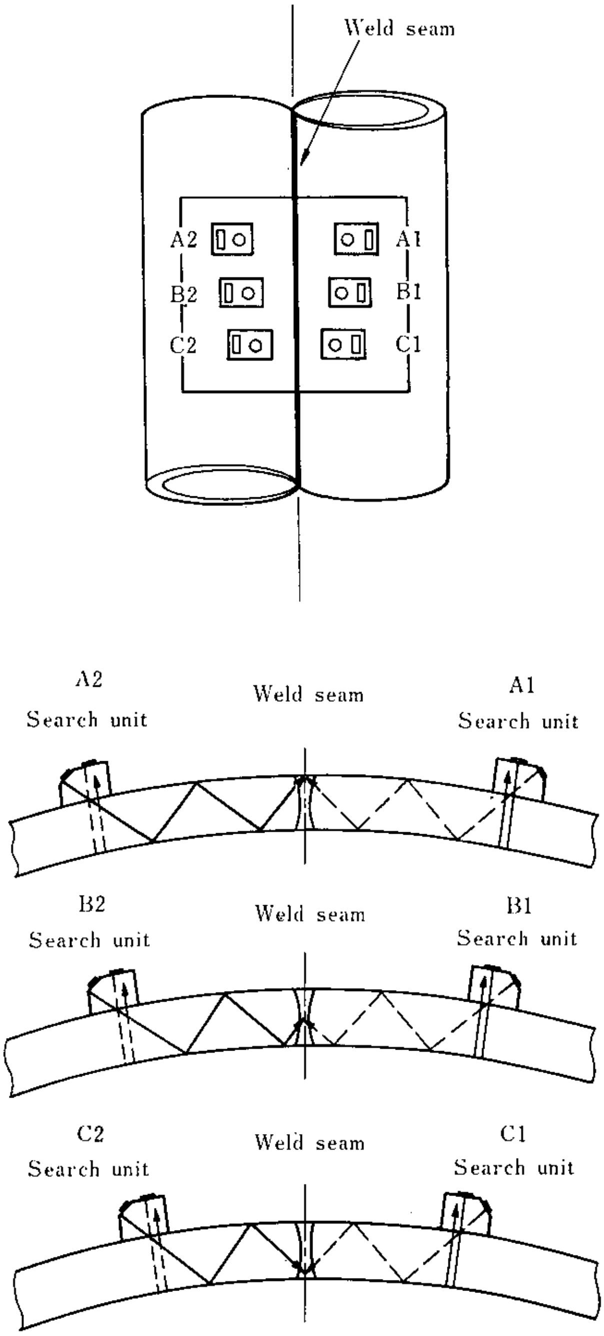


Fig. 12 Probe positioning of flaw detecting system by the water gap coupling method

4.2.3 Rotary probe type automatic ultrasonic testing system for full-body inspection

This system detects laminar flaws on the pipe body and can detect flaws over the entire length of the pipe formed. The system circumferentially scans the lamination of the pipe body extending in the rolling direction of the skelp, that is, in the longitudinal direction of the pipe, by means of the rotary probe method, thereby demonstrating high detection accuracy. For details of this system, refer to Par. 2.2.3. It is the largest rotary probe type automatic ultrasonic testing system in Japan and in the world that can detect flaws on medium diameter pipe measuring $6^5/_8$" to 26" in outside diameter. It was installed in 1979 and has been operating smoothly since then. It has been used principally for flaw detection of line pipe for sour gas service, and has received a favorable response from users.

In the above, inspection facilities mainly of the 26" ERW pipe mill were reviewed. In the 20" ERW pipe mill, the same inspection method is also used.

5 Small Diameter ERW Pipe

5.1 Manufacturing and Inspection System and Its Features

Chita Works has 6" and $2^1/_2$" ERW pipe mills in the same plant. The major products of this plant cover a wide variety of types and sizes of pipe, including casing, tubing for OCTG and line pipes, tubes for boilers and heat exchangers, steel tubes for machine structural purposes, steel pipe for pressure service, and steel pipe for ordinary piping. Consequently, non-destructive inspection systems are used appropriately according to the types and sizes of pipe. The general manufacturing and inspection process is shown in **Fig. 13**. Besides the above, tubing and casings for

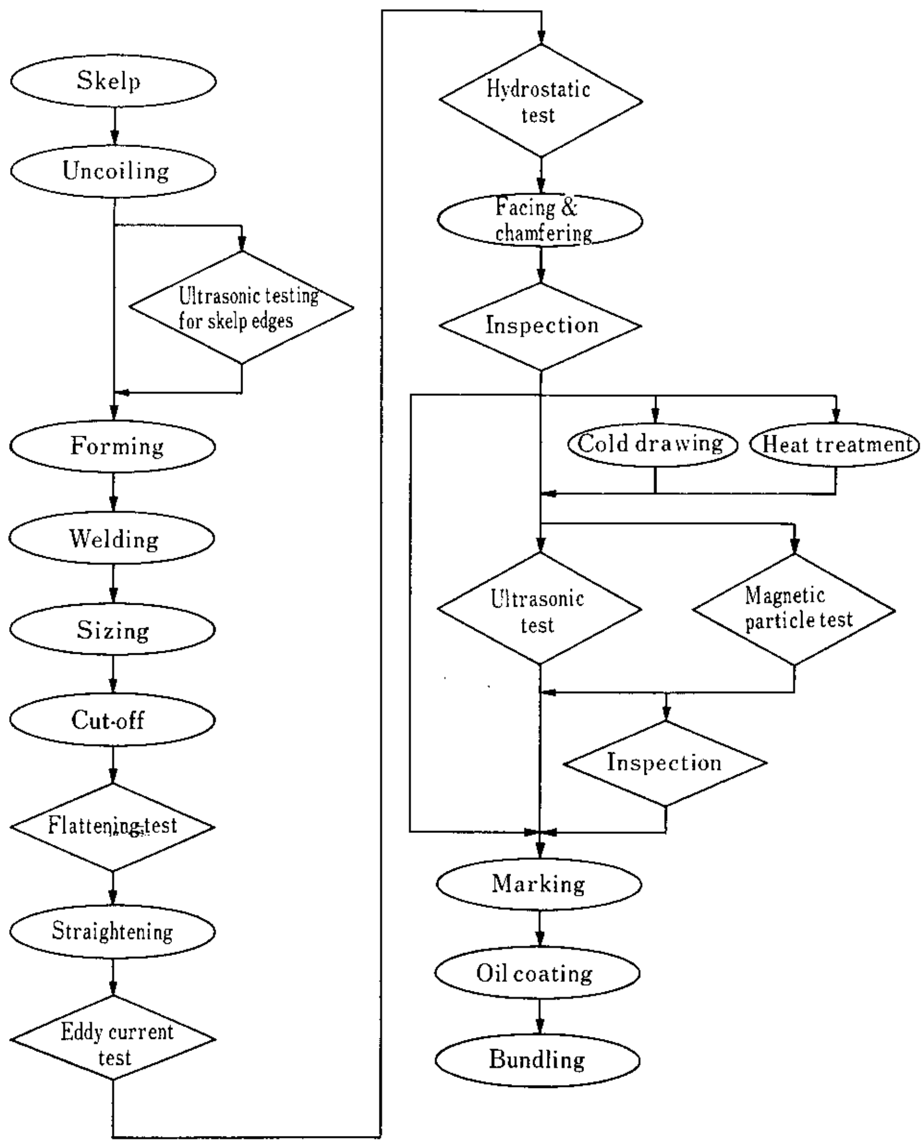


Fig. 13 Manufacturing process of small diameter ERW pipe

OCTG are completed by the same process as that in the small diameter seamless OCTG finishing line. Regarding the small diameter ERW pipe, improvements in the manufacture of hot coils and pipe and progress in nondestructive inspection techniques have resulted in the introduction of ERW pipe into fields where previously only seamless tubes were used.

5.2 NDI Systems

5.2.1 Eddy current flaw detector

Both mill lines are provided with an on-line eddy current flaw detector each to perform total inspection. The flaw detection method and its features are the same as those of the flaw detector for small diameter seamless tubes.

The eddy current flaw detector which has been recently introduced, in particular, has the following features to achieve improvements in accuracy and efficiency[7].

(1) The detector has an automatic sensitivity-setting function, and sensitivity-setting can be made automatically by travelling a pipe on which artificial flaws are machined.

(2) It is provided with a residual image type CRT, and phase adjustment can be easily made by causing flaw signals to provide vector display on the CRT.

(3) It has an automatic gain and phase check function. It automatically checks the gain of the flaw detector and variation in phases and sends out an alarm, thereby making possible highly accurate flaw detection.

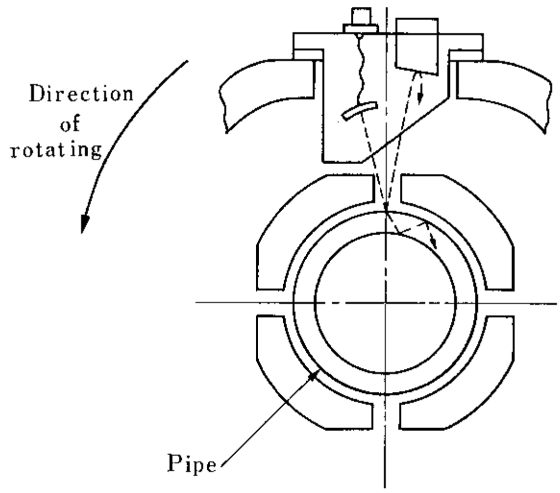
Besides the above, various improvements have been made to the electric circuit, detecting device and conveyor, thereby effectively contributing to the enhancement of the quality of ERW pipe.

5.2.2 Automatic ultrasonic flaw detector

This plant has two automatic ultrasonic testing detectors; one is installed at the 6" ERW pipe mill and detects flaws on welds by the angle beam method, the other is installed at the $2^1/_2$" ERW pipe mill and is an up-to-date flaw detecting system employing the rotary probe type automatic ultrasonic testing method, and has the following special functions and features:

(1) Like other newly introduced flaw detecting system, this system features:
   (a) Automatic sensitivity-setting by computer
   (b) Automatic printouts of testing conditions and results by the computer
   (c) Acoustic coupling monitor
   (d) Anomaly monitoring function by the flaw detector itself
   (e) Adoption of a rotary transformer for signal transmission

Mode	Detecting head	Probe arrangement and direction of beam			
1	0°	+L	+T		−L
	90°	+L		−T	−L
	180°	+L	−T		−L
	270°	+L		−T	−L
2	0°	+T	+L		−T
	90°	+T		−L	−T
	180°	+T	+L		−T
	270°	+T		−L	−T



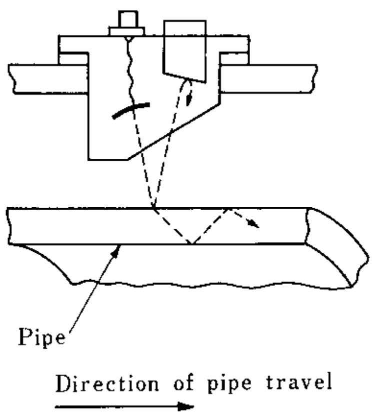


Fig. 14 Schema of rotary probe type automatic ultrasonic testing system for small diameter ERW pipe

(2) As shown in **Fig. 14**, two kinds of modes can be selected. In general, the detector is used for detecting longitudinal flaws, and in the case of cold-drawn tubes, alloy steel tubes, etc., it is used for detecting longitudinal and transverse flaws (Mode 2), so that it can be used properly according to the types and manufacturing methods of the pipe.
(3) For weld flaw detection, the system is so designed as to permit easy detection of even small flaws, and is provided with probes having the acoustic field suitable for detecting flaws on small diameter pipes with a large curvature.
(4) A design unique to Kawasaki Steel is applied to the guides for pipe that travels through the rotary probe-holder, and thus the detector can perform stabilized flaw detection on small diameter pipe.
(5) Pipe to be inspected is conveyed in the end-to-end state to enhance processing capability. This also makes it possible to prevent unnecessary water from entering in the pipe.

Since this system can detect not only shallow flaws on the weld but also inclusions in the pipe body, it is playing an important role in guaranteeing the quality of high grade pipe such as OCTG, boiler tubes, alloy steel pipe for machine structural purposes, etc.

5.2.3 Magnetic particle flaw detector for welds

This detector employs magnetization by the yoke and coil methods, as shown in **Fig. 15**, for detecting shallow flaws on the weld in the longitudinal and transverse directions simultaneously. It is used for pipe such as boiler tubes, automobile safety parts and quenched and tempered OCTG, which require detection of shallow flaws on the weld. The weld flaw detector is used in combination with the eddy current inspection and ultrasonic inspection to perform double or triple inspection. The weld flaw detector is generally used to detect longitudinal flaws, but in the case of alloy steel pipe, etc., flaws in both directions can be detected. In the latter case, the phase difference of currents that flow through the yoke and coil is arranged at an angle of 90°, and thus, it can detect flaws in any direction. Since the detector is of the continuous flaw detecting type, in which pipe to be inspected is applied with an inspection liquid and inspected under the ultraviolet light while passing through the yoke and coil, only a single attendant is required to ensure high-accuracy flaw detection[8].

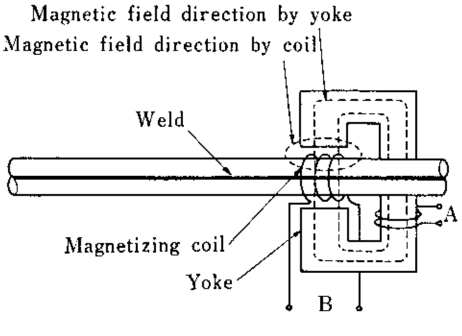


Fig. 15 Schema of magnetic particle flaw detector for weld of ERW pipe

6 Spiral Weld Pipe

Chita Works also has two spiral weld pipe mills. In addition, Kawasaki Steel's Chiba Works has the following large diameter pipe mills which operate under a strict inspection and control system whose details are omitted in this paper:

UOE pipe mill	1 unit	20 to 64″
Spiral weld pipe mills	2 units	16 to 80″
Bending roll pipe mill	1 unit	20 to 126″

6.1 Manufacturing and Inspection System and Its Features

Fig. 16 shows the manufacturing and inspection process of spiral weld pipe at Chita Works. Its major products include line pipe and pipe for structural purposes consisting mainly of steel pipe piles. In the manufacture of these pipe products, the X-ray fluoroscopic test and X-ray radiographic test are performed, but in the case of line pipe, other tests such as hydrostatic test and ultrasonic test of welds are used in combination, and the ultrasonic test for the pipe body is also performed for a part of the pipe. In this way, line pipe is subjected to inspection by X-ray test and ultrasonic test.

6.2 Nondestructive Inspection Systems

6.2.1 Ultrasonic flaw detector for pipe body

This detector performs laminar flaw detection on the pipe body immediately after forming and welding are completed.

The double crystal probe is driven by the scanning device which performs reciprocal motion, and the pipe travels, keeping pace with forming and welding. Therefore, scanning is performed by forming a locus of the sinusoidal curve. Thus the object of detecting flaws on the pipe body is accomplished with comparatively simpler equipment.

6.2.2 X-ray fluoroscopic testing equipment

This equipment enables flaw detection over the entire length of the weld of the spiral weld pipe. The shadowgraph on the fluorescent screen is enlarged and reproduced on a television screen for observation and flaw inspection.

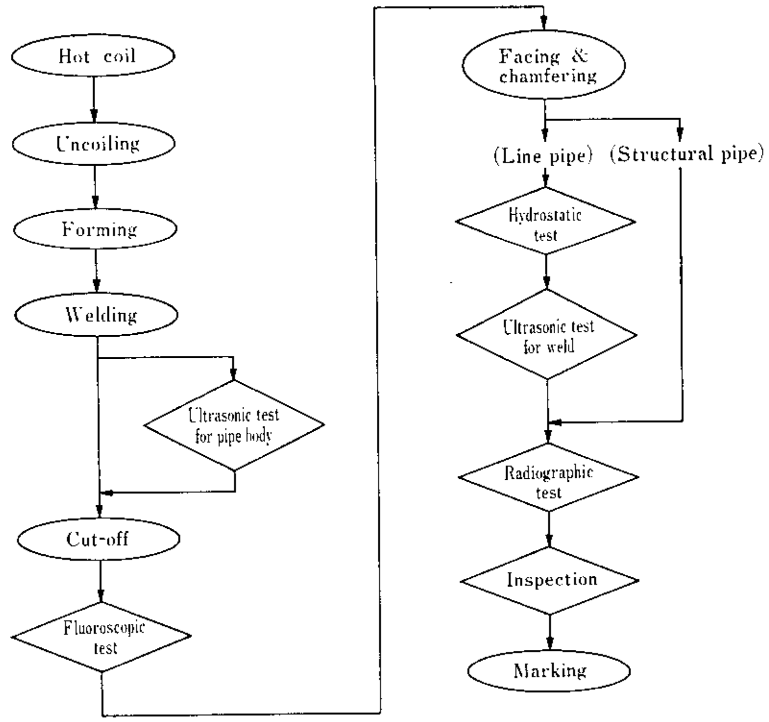


Fig. 16 Manufacturing process for spiral weld pipe

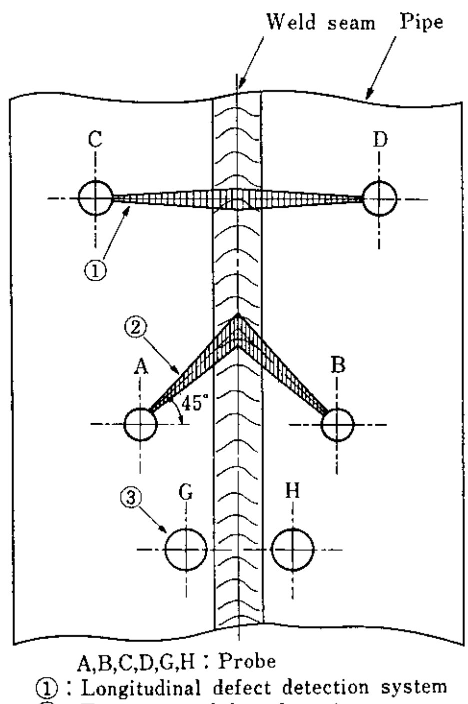
6.2.3 Automatic ultrasonic flaw detector for welds

This is the SNUP-Q Type Automatic Ultrasonic Flaw Detector made by Kraut Krämer-Branson International, West Germany, and is installed as an on-line finishing equipment immediately after the hydrostatic tester. The detector consists, as shown in **Fig. 17**, of two pairs of angle probes, which detect flaws in the weld-line direction and in the normal direction, respectively, and one double crystal probe each is located on both sides of the weld zone for detecting laminar flaws near the weld zone. Flaws on the weld zone are detected from both the right and left sides of the weld line, thereby ensuring high accuracy flaw detection without being adversely influenced by the difference in echo heights due to flaw shapes and the effect of echoes due to weld beads.

The weld flaw detector is additionally equipped with an automatic seam guiding device utilizing the electromagnetic method which maintains a constant distance between the weld line and the probe, thereby performing correct flaw detection. Further, the detector has an acoustic coupling monitor to ensure highly accurate flaw detection.

6.2.4 X-ray radiographic testing device

X-ray radiographic tests are conducted on pipe ends and other locations where such tests are necessary.



A,B,C,D,G,H : Probe
① : Longitudinal defect detection system
② : Transverse defect detection system
③ : Laminar defect detection system

Fig. 17 Schema of automatic ultrasonic flaw detector for weld of spiral weld pipe

7 Continuous Butt-Weld Pipe

7.1 Manufacturing and Inspection System and Its Features

Chita Works is also manufacturing pipe for ordinary use with high efficiency by the Fretz Moon process, and the pipe making speed has reached a maximum of 450 m/min. It is also provided with galvanizing and threading facilities for steel pipe. The manufacturing and inspection process of continuous butt-weld pipes is shown in **Fig. 18**. After the dividing line, the manufacturing process is divided into two lines, and after the straightener, an eddy current flaw detector is installed on each line to detect flaws on every piece of pipe along its entire length. For pipe for important or special applications, high accuracy flaw detection is performed with an off-line eddy current flaw detector, thereby performing double inspection.

7.2 NDI Systems

As mentioned above, this plant is provided with 3 units of eddy current flaw detectors, all of which employ the encircling coil type self-comparison techniques. Particularly, special consideration is given to the on-line detectors concerning the arrangement of the conveyor rolls, so that their high inspection speed is not hampered.

8 Technical Development System on NDI

The need has been keenly felt recently for the development of NDI methods and equipment which correspond to the expansion of steel pipe applications and development of new products and processes and which suitably match the users' needs. Also in order to reduce manufacturing costs and save energy, it is

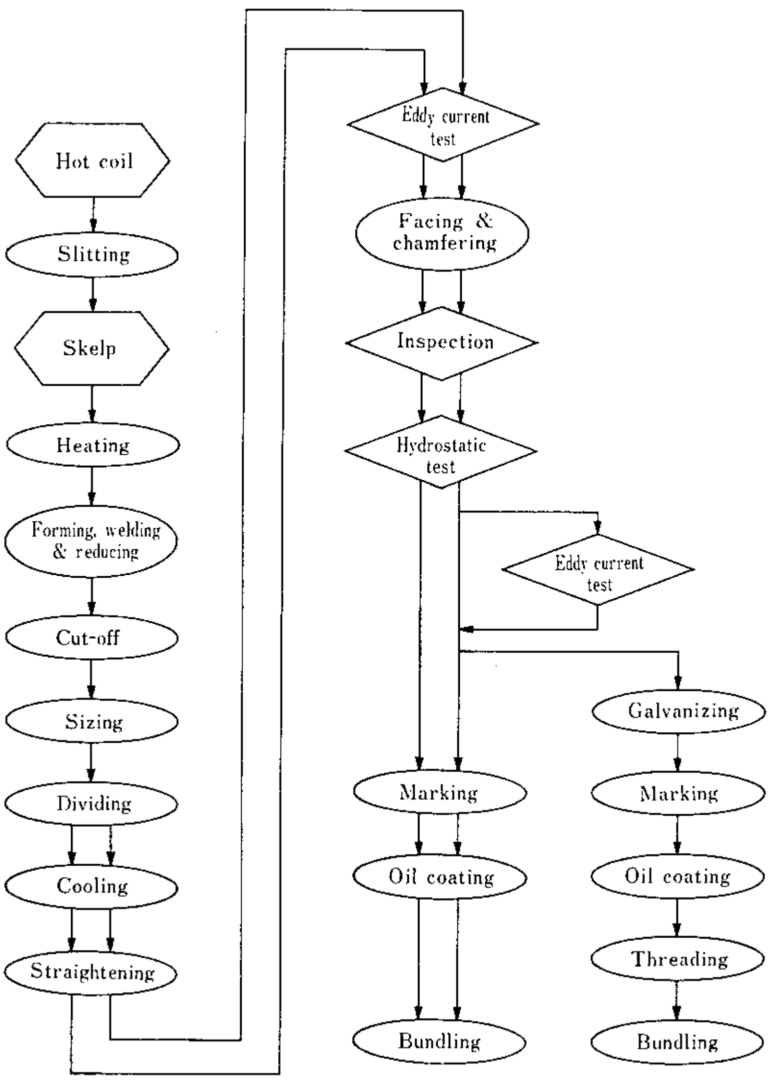


Fig. 18 Manufacturing process of continuous batt- weld pipe

necessary to promote the development of new equipment and automation of existing equipment. To achieve this, research on both hardware and software is required. Particularly, studies on detectability of actual flaws, processing capability and workability of equipment as well as on the optimum methods and equipment are very important.

These researches in Kawasaki Steel are conducted in close cooperation and by sharing of responsiblities between Research Laboratories (in particular, Instrumentation Laboratory and Measurement and Instrumentation Center) and in-plant organizations (in particular, Inspection Section and Equipment and Engineering Section).

As an organization for formulating research and development plans, for grasping the progress of such plans, and for exchanging technical information, the NDI Committee of the Inspection Technique Council is established, and by holding a semiannual conference of the Committee, management of research and development is smoothly conducted.

9 Control System of NDI Systems

9.1 Standardization

When the method and equipment for NDI are determined and the equipment is introduced, it is necessary to check the flaw detectability of the equipment, and on the basis of this investigation, an operating procedure is determined and compiled. In this case, technical standards are determined which contain various specification and users' requirements. When the technical standards are stipulated or revised, training of inspectors is undertaken on each occasion.

9.2 Checking and Maintenance of Equipment

Since trouble with the NDI equipment in a pipe manufacturing plant may result in the stoppage of the manufacturing line, checking and maintenance of the inspection equipment are important. For this reason, daily checking by operating divisions and periodical checking and maintenance by the Instrumentation and Control Section and resultant modification for improvement are performed.

10 NDI Personnel Qualification System

Qualification of NDI system operators at Kawasaki Steel is determined on the basis of the following two systems:

(1) Kawasaki Steel's company qualification system
In this system, company rule is established on the basis of the SNT-TC-1A Standards and training and education stipulated by the TC-1A Standards are executed. Then the trainees are subjected to qualification examinations for qualification of Levels III, II, and I according to the test methods of RT (radiographic testing), UT (ultrasonic testing), MT (magnetic testing), PT (liquid penetrant testing) and ET (electromagnetic testing).

(2) Qualification by JSNDI (Japanese Society for Nondestructive Inspection)
The JSNDI performs semiannual qualification examinations and certifies 1st, 2nd and 3rd grade NDI personnel according to the testing methods of RT, UT, MT, PT, ET, and SM (strain measurement). In order to meet the demands of domestic users and to promote the skills of inspectors, Kawasaki Steel is encouraging its personnel to acquire the qualification.

11 Conclusion

NDI of steel pipe at Chita Works is performed by using equipment and control system which provide quality assurance for various pipe products of different types, sizes, grades and applications.

However, the environmental conditions under which pipe is used are changing, and accordingly higher-quality products are now in demand. Therefore, Kawasaki Steel will continue to search for higher grade NDI system in the future.

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Data Sheet: Pipe-Making Facilities

Production process	Manufacturing method		Number of mills	Start of operation (year)	Works	Annual capacity (t/year)	Available size range(mm)		Main products
							Outside diameter	Wall thickness	
Seamless	Mannesmann mandrel mill	Hot Fin.	1	1970	Chita	270 000 (444 000*)	21.3-168.3	2.3-18.5	•Standard pipe •Line pipe •Pressure tube •Boiler tube •Heat exchanger tube •Mechanical tube •O C T G
		Cold Fin.	1	1972	〃		12.7-114.0	1.2-12.0	
	Mannesmann plug mill		1	1978	〃	180 000 (384 000*)	177.8-426.0	5.0-40.5	
E R W	High-frequency induction welding		1	1974	〃	120 000	50.8-168.3	1.2-11.0	•Standard pipe •Structural pipe •Line pipe •Coating pipe •Pressure tube •Boiler tube •Heat exchanger tube •Mechanical tube •O C T G •Pipe pile
	〃		1	1972	〃	36 000	21.3-76.3	1.0-7.0	
	High-frequency resistance welding		1	1964	〃	240 000	165.2-508.0	2.7-14.7	
	〃		1	1978	〃	180 000	267.4-660.4	4.0-16.0	
C B W	Continuous butt weld pipe mill		1	1971	〃	288 000	21.3-114.3	2.0-8.6	•Standard pipe •Structural pipe •Galvanized pipe
S A W	Spiral weld pipe mill		2	1961	〃	96 000	400.0-1 524.0	4.0-14.0	•Standard pipe •Line pipe •Structural pipe •Coating pipe •Pipe pile
			2	1967	Chiba	100 000	400.0-2 032.0	4.0-22.0	
	U O E pipe mill		1	1974	〃	480 000	508.0-1 625.6	6.35-38.1	
	Bending-roll mill		1	1970	〃	30 000	450.0-3 200.0	6.0-32.0	

*Scheduled in April 1982