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1 Introduction

A project for revamping the continuous bloom caster and building a new billet mill was conducted at Mizushima Works. With an ultimate goal of advancing a bloom manufacture rationalization while improving the quality assurance performance level, it was planned to establish a well synchronized and continuous system for the CC and billet rolling by integrating into the new billet mill all the billet rolling operations that used to branch out into three plants, including the wide flange beam mill and an old billet mill.

A synchronized operation of continuous manufacturing processes presupposes an attainment of high quality level in each individual manufacturing process and an establishment of a sound quality assurance system for an on-line factual evaluation of product quality. In the CC plant and new billet mill, measures for these purposes were taken in the manufacturing processes for molten steel, blooms, and billets, in order to establish an integrated quality assurance system.

This paper describes the functions and features of the integrated quality assurance system, covering the manufacturing specification design, quality judgment, quality assurance inspection facilities, and a sound piecewise tracking control, and gives an outline of actual quality records of manufactured billets and seamless pipes.

2 Aims and Mechanism of Quality Assurance

Continuous operation of the CC plant and billet mill has been achieved on the basis of the sound quality assurance system with the principal aim of manufacturing products to design quality. This requires, on one

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hand, manufacturing equipment which can maintain high product quality in each process, and, on the other hand, devices which can issue manufacturing instructions specifying adequate operating conditions to such equipment and a sound system to evaluate and inspect the quality of manufactured products.

Particularly in continuous operation, rejects due to defective quality are liable to cause operation shutdown, and therefore it is indispensable to realize high quality at each manufacturing stage. Points which were given careful consideration in connection with equipment are described in detail in Sec. 3.1.

Design of manufacturing specifications, transmission of instructions, and on-line quality judgment are supported by a three-tier hierarchy comprising the central computer (C/C), on-line computers (O/C), and process computers (P/C)[1]. The roles of the respective computers are shown in **Fig. 1**. Manufacturing specifications are automatically designed by C/C, and transmitted through O/C to P/C. Information on actual results travels the same route in the reverse direction and is accumulated in the control-analysis D/B. Quality records are evaluated and judged in two stages, i.e., in an on-line quality judgment by O/C and in a direct product inspection by such devices as the surface flaw detector. Along these lines the quality judgment system has been developed, and quality assurance facilities such as the bloom and billet hot surface flaw detectors have been actively introduced.

To achieve effective functioning of the above mechanisms, all actual products are continuously tracked to effect piecewise control. Products are stamped and labeled, so that even if a billet in transport to the next process deviates from the tracking range, it can be accurately identified.

For the seamless pipe produced at Chita Works, shortening the lead time between order receiving and shipment and improving through-yield have posed serious problems. To cope with these problems, Mizushima Works, which supplies billets to Chita, has developed a material design system for producing design billets which takes into consideration pipe-making lots at Chita Works in the cut-billet orders which Mizushima receives from Chita. To obtain design cut billets consistently, it is necessary to secure the required weight of calculated-length billets and blooms. To achieve this weight assurance, the cutting facilities, such as the torch and hot saw, are provided with on-line scalers to perform weight judgments. When deviation from the target occurs, this information is fed back to the mill and cutting facilities to allow them to adjust the cut length to guarantee the specified billet weight.

3 Quality Assurance in Continuous Processes

3.1 Consideration for Quality Improvement

Points given consideration as measures for improving product quality at manufacturing lines and for ensuring stabilized high quality are given below.

(1) Continuous Casting Machine[2]

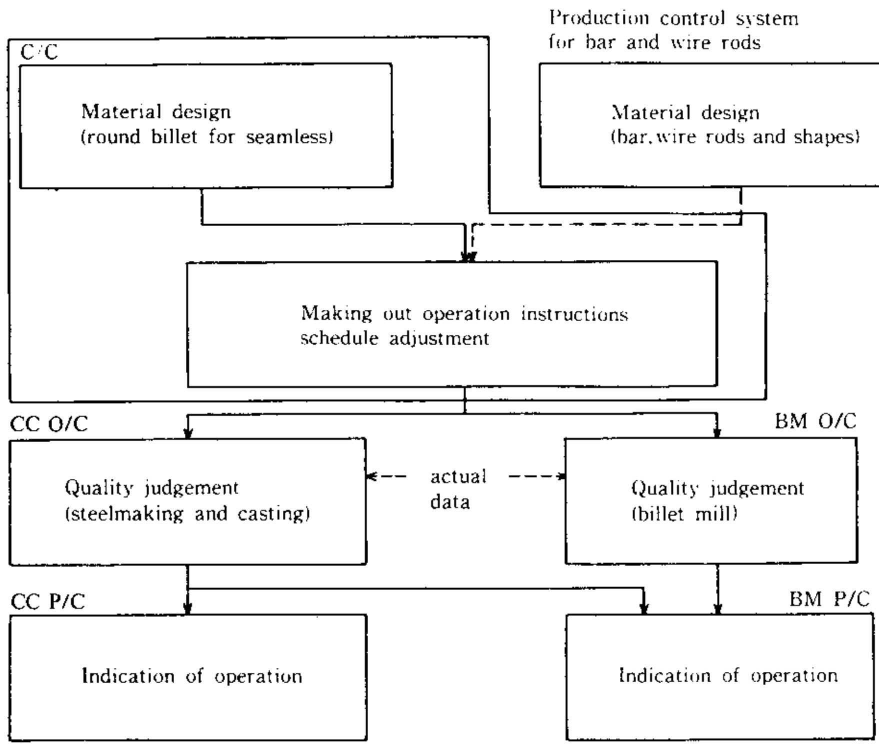


Fig. 1 Schema of quality assurance system

(a) Decrease in Nonmetallic Inclusion and Reduction in Central Segregation
  (i) Increase in tundish capacity
  (ii) Decrease in the number of strands from 8 to 6
  (iii) Installation of mold with larger cross section
  (iv) Installation of EMS at crater end
(b) Decrease in Bloom Surface Defects
  (i) Improvement in mold oscillation mechanism
  (ii) Use of mist spray at secondary cooling zone

(2) New Billet Mill
(a) Improvement in Dimensional Accuracy
  (i) Improvement in reduction stopping accuracy at roughing mill (1.0 mm → 0.2 mm)
  (ii) Adoption of high rigidity finishing mill (mill constant: 300 tf/mm)
  (iii) Temperature control at extraction end of reheating furnace and stabilization of material control by furnace-width-direction tapered heating control
(b) Improvement in Internal Quality
  (i) Uniformity of surface and center temperatures by high-temperature charging into reheating furnace
  (ii) Stronger reduction rolling at roughing mill
(c) Decrease in Surface Defects
  (i) Restraint of scale generation by O_2 control at reheating furnace
  (ii) Installation of mill descaler
  (iii) Prevention of abrasion scratches during transportation, by adoption of a chain transfer system

3.2 Development of Material Design System for Round Billet for Seamless Pipe

A raw material design system has been developed to shorten lead time and improve through-yield.

Mizushima Works receives order for billets in terms of multiple number of cut billet which is minimum unit of lots chargeable into the reheating furnace in pipe-making at Chita Works. In Mizushima Works, calculated-length long billets, blooms, heats, and casts at integer-multiples of cut billet weight are designed, and according to this design, manufacturing instructions are given to the CC plant and billet mill, so that cut billets are accumulated to maximize the through-yield between raw material and pipe, while free from the need of any extra control during manufacture such as the rearranging of lots and length assorting calculations.

In the production line, designed pipe-making lots are manufactured as designed by the piecewise tracking of products and a transportation sequence assurance mechanism. Further, the billet surfaces flaw detection and, after detected defects have been completely removed by grinding, the billets are sent to Chita Works. Through the above procedure, operations at the Chita material yard is reduced to the splitting of billets and charging them into the reheating furnace, permitting a noticeable decrease in the amount of billets in stock, the shortening of lead time, and improvement in through-yield.

3.3 Piecewise Tracking

Piecewise control of blooms or billets is an essential part of a sophisticated quality control. In a synchronized continuous operation, billets must be forwarded without disturbing the rolling lot in the next process, and this rquires a fault-free tracking of workpiece and an assurance of the piecewise transportation sequence. Between the CC plant and new billet mill, tracking by P/C begins immediately when the bloom is cut by the torch cutter. Subsequently, computerized piecewise tracking is performed without interruption through transport by the highly computer controlled vehicle (HCCV), reheating furnace, mill-line, cooling bed,

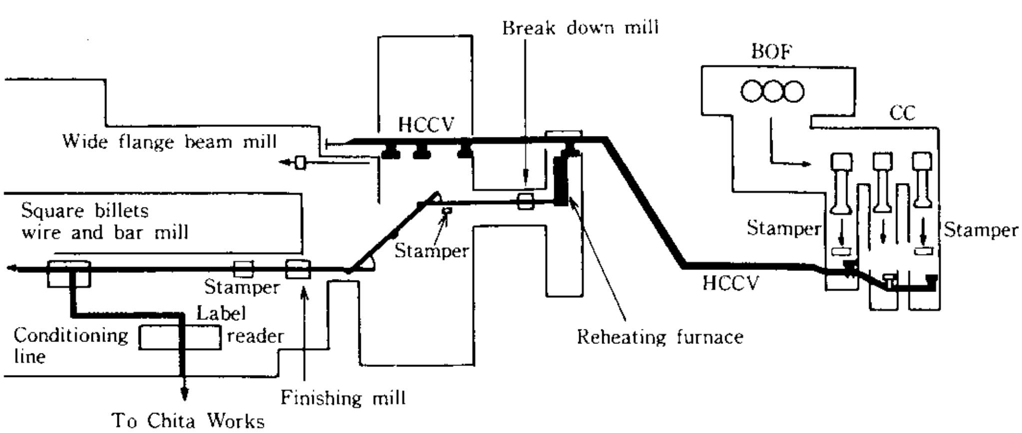


Fig. 2 Tracking area of bloom and billet

finishing line and to delivery. The scope of tracking is shown in **Fig. 2.**

Further, products are marked and labeled to ensure unmistakable identification. Identification numbers are as follows:

Blooms: Hot marking after torch cutting (7 alphanumeric digits)

Billets: Hot marking (7 alphanumeric digits) after hot saw cutting and labeling after cooling

Even if piecewise control is effected completely, the bloom transportation sequence is sometimes reversed because with a multiple-strand continuous bloom caster, torch cutting completion timing may vary between strands due to casting problems. To prevent this reversal of sequence and ensure the transport of blooms according to the design sequence, the cutting method shown in **Fig. 3** has been adopted. In the cutting instructions, a sequence for piecewise cutting is specified. Cutting instructions are sequentially allocated to blooms starting with the bloom first pulled from the strand to the torch cutter. If rejects or a casting-stop strand occur during casting, the problem blooms are removed from the line and instructions are reallocated, thereby ensuring the proper transport sequence for good products. The layout of the continuous-casting transport line is shown in **Fig. 4.**

The details of billet tracking are described in the separate report[3] entitled "Advanced Instrumentation and Full Automatic Control System of the New Billet Mill".

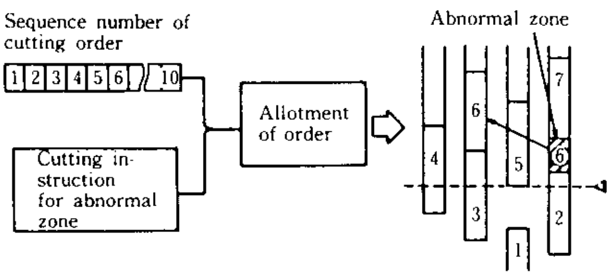


Fig. 3 Allotment of order for cutting

3.4 On-line Quality Judgment

3.4.1 Automatic design of manufacturing specifications

Quality designs which will satisfy the quality requirements of orders accepted are made for each product line quality design. Quality design systems for the CC and billet mill line prepare automatic designs of manufacturing conditions necessary to assure design quality, as well as steel-making and rolling instructions. The O/C checks the actual operation data against specification instruction, to perform quality judgment. The aforementioned manufacturing specification standard is classified into standard specifications, special specifications, and experimental specifications.

3.4.2 Judgment of molten steel chemical composition

The target values and control limit values of chemical composition are specified by the steelmaking instructions. A maximum of 57 kinds can be specified simultaneously.

(1) Number of elements — 32 kinds

(2) Composite items such as Ni + Cr and Mn/S — 9 kinds

(3) Carbon equivalent (calculation formula and control limit value) — 16 kinds

The O/C checks the actually analysed value, which has been transmitted by the analysis P/C, against the control limit value, thereby giving judgment on the following four items:

(1) Ladle representative analysis

(2) Ladle analysis of the sample taken at the last portion

(3) In-ladle segregation (The difference between "representative" and "at the last portion" is controlled within a specified limit.)

(4) Continuous-continuous joint judgment (Analysis value of the adjoining heat is also assured within a control limit.)

If actual results are judged to have deviated from control

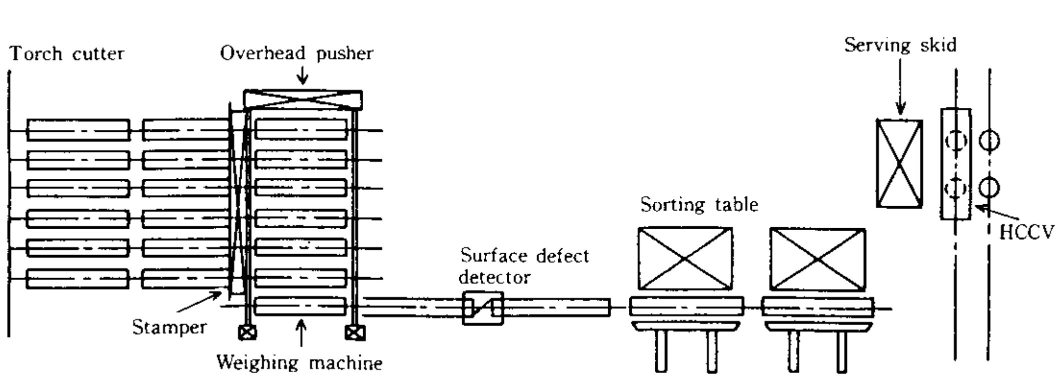


Fig. 4 Layout of discharging line

limit, O/C determines adjustments such as changes in torch cutting length and check analysis instructions and gives instructions to P/C.

3.4.3 Operation judgments of CC plant and new billet mill

In the operation system, P/C collates actual operation data with the operation standard value which it has been given, and the control limit values transmitted as manufacturing instructions. When limit values are exceeded, the P/C judges the product as abnormal. The "judged abnormal" information is transmitted to O/C to determine the scope of special control applicable to the abnormal quality product and the disposal method. Items to be judged in CC operation are shown in **Table 1**, and Items to be determined in billet mill operation are shown in **Table 2**.

Further, the judgment result is transmitted realtime to the next process for use as an operation index: For instance, in the case of a surface flaw with a CC bloom, instructions are given to the hot scarfer in the billet mill. When an operator detects an abnormality, he will manually input the abnormality code into his terminal to automatically determine the control scope and disposal method of the procuct.

3.5 Inspection Facilities for Quality Assurance

Quality assurance in the continuous process between CC and rolling poses important problems such as:

(1) Control of hot surface quality
(2) Control of cold surface quality
(3) Establishment of pieceqwise traceability of the above-mentioned quality information and the docking of the piecewise tracking system to the surface conditioning unit

Inspection on hot surfaces is classified, as shown in **Fig. 5**, into surface defect detection at the bloom stage and at the intermediate billet stage. A suitable defect detection method is applied to meet the defect condition and bloom surface property at the respective stages. In the bloom stage, hot shot blast and optical defect detection methods have been adopted with the aim of detecting comparatively coarse defects under such limitations as the presence of oscillation marks inevitable in CC products and wide fluctuations in surface temperatures. Through the use of these methods, the degree of defect generation on the bloom is measured and fed back to CC operation.

Since the hot surface of the billet stage is an as-rolled surface and its temperature is stabilized at 850°C or above, a hot eddy current testing device is installed on the transfer roller table between the breakdown mill and billet mill. Defect detection by this device aims in particular at the non-conditioning sorting of square billets for wire rods and bars and at the detecting of seam defects, scale defects, and scabs measuring 1.0 mm minimum in depth, 0.1 mm minimum in opening, and 10–120 mm in length.

For cold defect detection, the full-auto magnetic leakage flux testing method and magnetic particle testing method have been adopted to inspect billets for the seamless pipe making at Chita Works and hot-rolled large-sized bar steels. After performing automatic defect marking by the magnetic leakage flux testing device, defects are removed by grinding. Omission of grinding and passing of defects are prevented, again, by the use of magnetic particle testing device, ensuring complete defect detection.

Defect information detected by these defect detectors is collected by P/C as quality information by billet, and transmitted to C/C as process record information after hot saw cutting. A data base totalling 5000 characters is

Table 1 Main items of quality judgement on continuous casting operation

Process	Items
Tundish	1) Temperature of molten steel in tundish 2) Weight of molten steel in tundish 3) Type of air sealing between ladle to tundish 4) Type of refractory lining in tundish
Mould	1) Casting speed 2) Deviation of metal meniscus 3) Type of mould powedr 4) Type of immersed nozzle 5) Oscillation cycles and pattern
Secondary cooling and pinch roll zone	1) Flow rate of mould spray water 2) EMS conditions (Amp. Hz) 3) Roller apron gap
Torch cutter discharge line	1) Bloom weight 2) Bloom cutting length

Table 2 Main items of quality judgement in billet mill operations

Process	Item
Furnace	1) Total heating time 2) Holding time on high temperature of bloom surface 3) Holding time on high temperature of bloom core 4) Maximum surface temperature during heating 5) CO concentration in waste gas 6) O_2 concentration in waste gas
Break down mill line	1) Bloom weight 2) Bloom cutting length
VH mill line	1) Billet weight 2) Billet cutting length

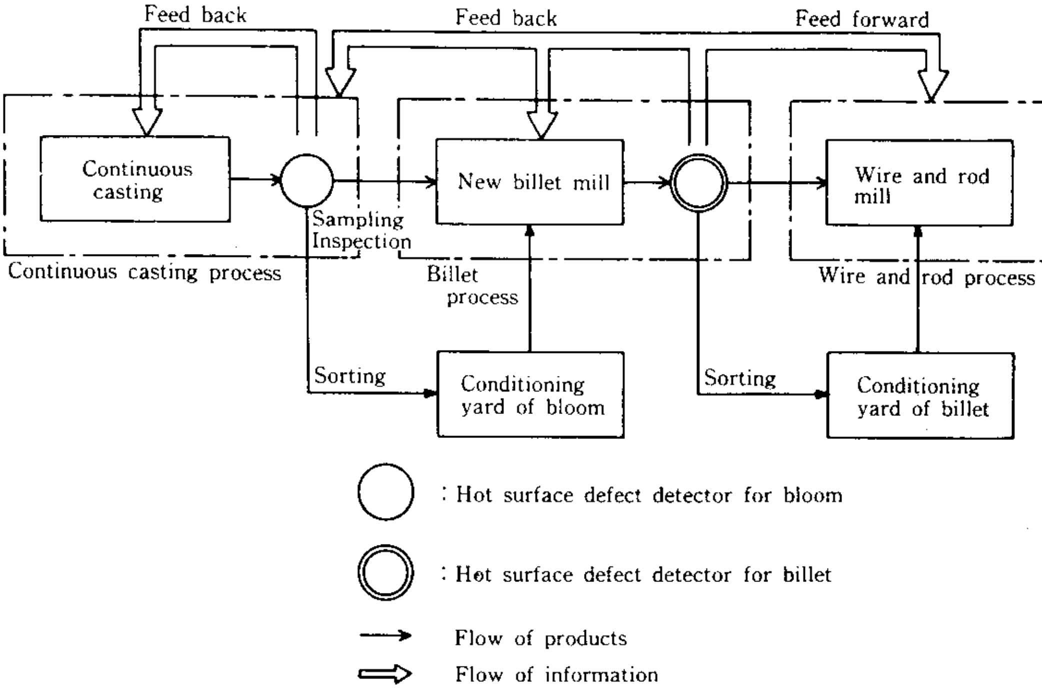


Fig. 5 The position of the hot surface defect detectors in the quality assurance system

compliled for each billet.

3.5.1 Bloom hot surface defect detection[4)]

A CC hot surface defect detector has been installed at No. 1 CC machine discharge line. Types and sizes of defects to be detected by the defect detector are shown in **Table 3**. The detector can discover all defects including planar defects such as scabs and rough surfaces, linear defects such as longitudinal and transverse cracks and dotty defects such as blowholes.

Major specifications of the defect detector are shown in **Table 4**. To detect the defects shown in Table 3, the detector uses a 1024-bit photodiode array and has a scanning speed of 2 ms/scan. Since its line speed is 22 m/min, a single scanning line corresponds to a bloom surface length of 0.73 mm in the longitudinal direction. The constructon of the defect detector is shown in **Fig. 6**. All four sides of a bloom are inspected for defects, with detector heads installed separately on the respective surfaces. The detector heads incorporate a light projector and a defect-detecting camera.

The signal processing unit has the following functions, taking into consideration cases of a manual intervention of operators in defect detection:

(1) Compressive processing of background signals of the bloom surface emphasizing treatment of the defect.

(2) Low-speed reproduction of the picture for ease of the operator in making judgment.

The projection volume of hot shots blast has been set

Table 3 Defects to be detected by optical method in delivery line of No. 1 continuous casting machine

Defect	Detection target (minimum size)
Rough surface	100 mm length
Scab	50 mm diameter
Crater	20 mm length
Depression	100 mm length
Cavity	200 mm diameter
Transverse corner crack	2 mm depth, 30 mm length
Scratch	1 mm depth, 100 mm length
Blowhole	3 mm diameter
Longitudinal crack	30 mm length
Cross crack	30 mm length

Table 4 Specifications for hot surface flaw detector at the No. 1 continuous casting machine

Item	Specifications
Line speed	22 m/min
Image sensor	Linear array image sensor 1 024 elements
Scanning period	2 ms
Field of view	400 mm
Signal processing	Image enhanced
Image display speed	½ ~ 1 time as fast as line speed

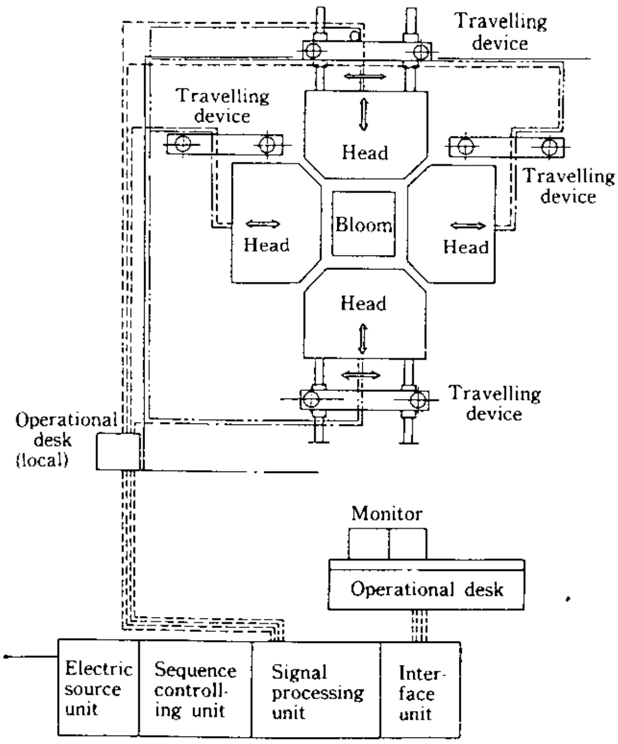


Fig. 6 Schema of hot surface defect detector for blooms

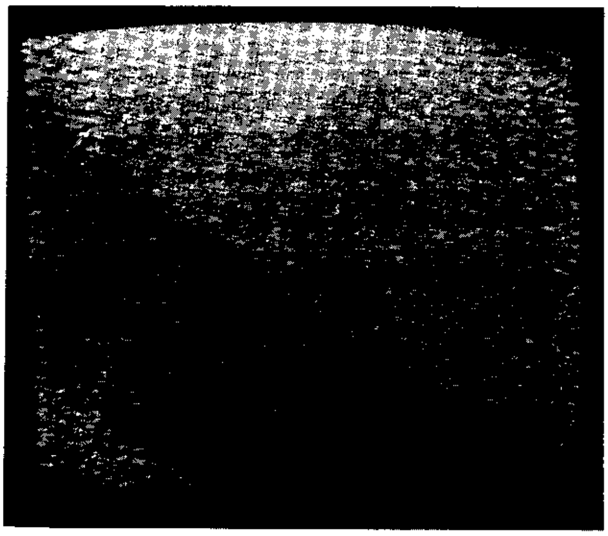


Photo 1 Enhanced CRT display of detector (bloom surface after shot blasting)

to 36 to 40 kg/m^2. If this value is not reached, scales will remain on the surface, and if this value is exceeded, shot grain traces become excessive. In both cases, the S/N of defect detection signals will be lowered.

Photo 1 shows a picture obtained by photographing the bloom surface with the defect detector after a hot shot blast and then applying signal processing. Background signals from the bloom are equalized and the defect is emphasized in black (arrow in Photo 1). The operator views this picture and judges the presence or absence of a defect.

Whether hot surface defect detection is necessary or not is judged and defect detection instructions are given for each piece of blooms at the time of compiling CC instructions. On the basis of these instructions, P/C tracks blooms which will require defect detection and controls the shot blaster and defect detector for individual blooms.

The defect detection results are used to judge whether the bloom should be hot-charged or not, how to treat blooms not requiring defect detection, and whether or not the operation can be continued.

3.5.2 Billet hot surface defect detection

This defect detector was described in a separate report[5] entitled "Revamping to Billet Mill for Continuous and synchonized Operation". It features seam defect detection by the fixed head probe system on the hot bloom surface. As a defect detection method, the rotary probe system was also examined, but it possessed such demerits as a complicated structure, as well as difficulties in corner defect detection by the rotary probe and incorporation of the detector in the production line. Consequently, the fixed head system has been developed. Problems in developing this system were:

(1) Variations in the detection characteristics of the probe with respect to defect shapes
(2) Detection characteristic variations dependent on the position at which the defect passed under the probe
(3) Output characteristic variations with the angle between the defect and the probe.

Thus the main point of development was to clear the previous detection limit of the fixed head probe for seam defects. The above-mentioned problems were related to determining the optimum shape and number of channels of the squareshaped probe. Through the experimental verification, it has been proved that the fixed head probe can satisfactorily detect seam defects on the as-rolled surface.

The coil shape and the output characteristics of an artifical defect are shown in **Fig. 7**. It has been found that a probe with a $l{:}l'{:}l$ ratio of 8:4:8 is most suitable for the fixed type. The relation between the defect advancing angle to the probe and the signal output is shown in **Fig. 8**. The probe is capable of showing stabilized output characteristics virtually unaffected by the defect advancing angle. Next, **Fig. 9** shows the characteristics data of the probe which determine its effective detection width. The range which allows an output fluctuation of ±7.5% with respect to a defect with a depth of 1.0 mm is ±6 mm. Assuming that this is the effective detection range of the probe, a fixed-head type eddy current test-

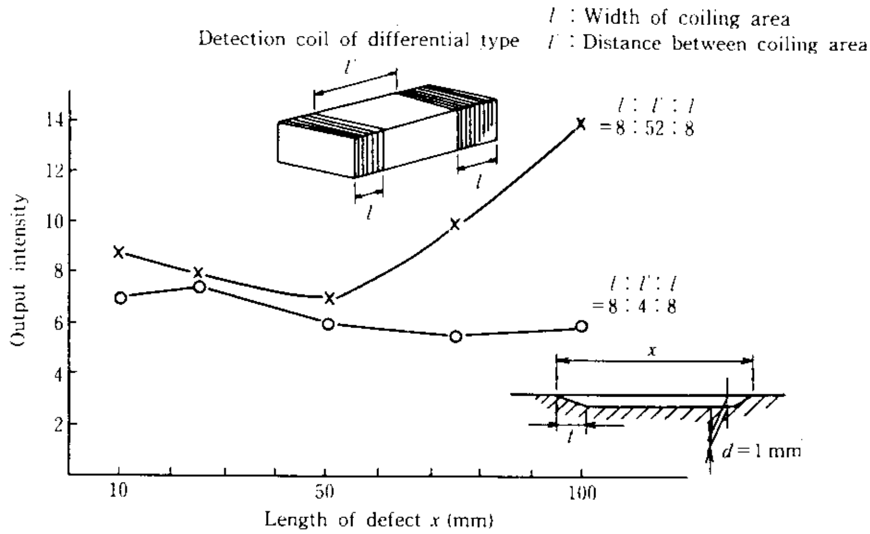


Fig. 7 Output characteristics and dimensions of detection coil (by artificial defect)

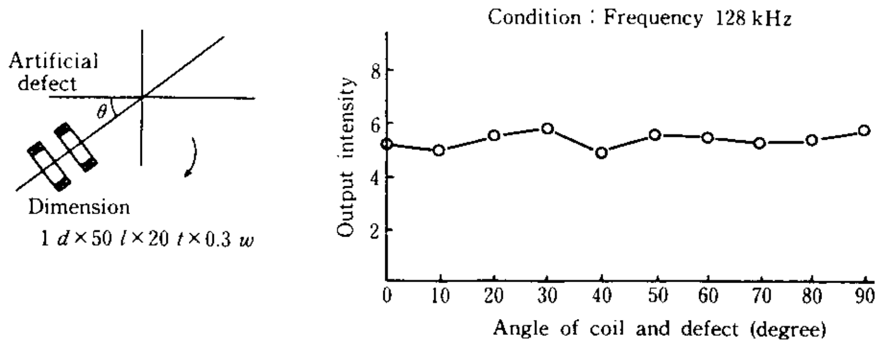


Fig. 8 Relation of signal intensity and angle of coil and defect

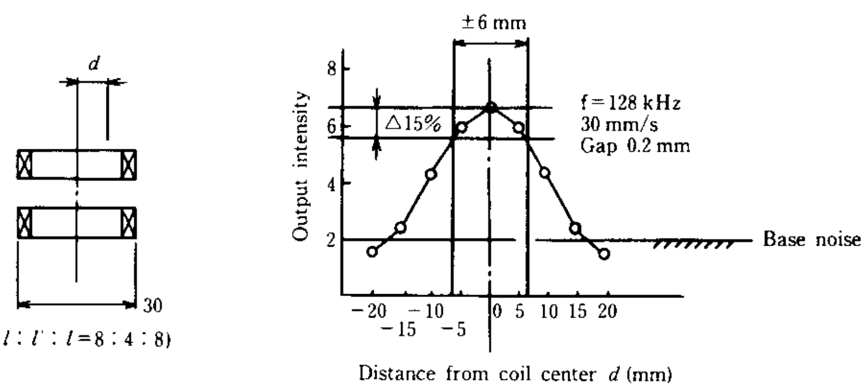


Fig. 9 Effective area of detection coil in the width direction

ing device has been developed which is of the multi-channel type with 21 channels for a single unit including the corner, or 84 channels in total.

A front view of the eddy current testing device is shown in **Fig. 10**. Pinch rollers are provided at the front and rear of the device, and an air cylinder type centering device is provided at the inlet. Calibration is performed as follows: At the off-line calibration position, a double-row reciprocating operation system is used to perform full-auto 4-side calibration using an artificial defect of 1 mm in depth on the stainless steel surface. The probe is cooled by fresh-water circulation at a flow rate of 350 *l*/ min. The defect detecting speed is 1.0 m/min.

Figure 11 shows the results of investigation of detectability for a hot artificial defect, both on a flat surface and at a corner, using phase angles. It has been found that

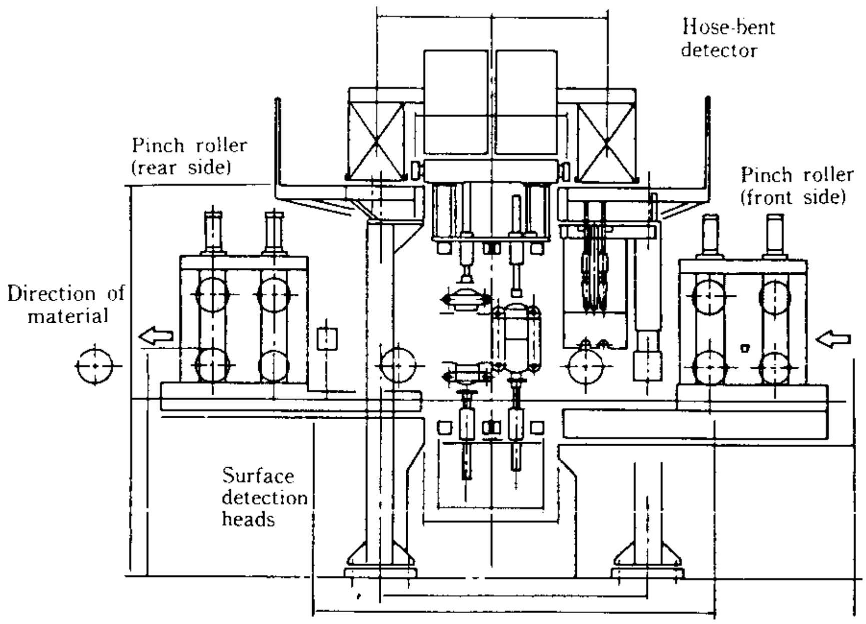


Fig. 10 Front view of hot eddy current testing device

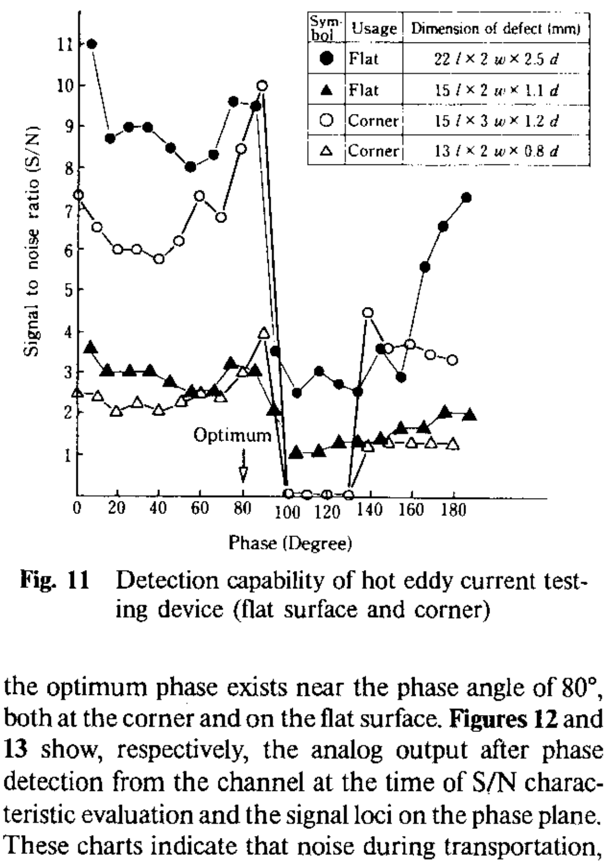


Fig. 11 Detection capability of hot eddy current testing device (flat surface and corner)

the optimum phase exists near the phase angle of 80°, both at the corner and on the flat surface. **Figures 12** and **13** show, respectively, the analog output after phase detection from the channel at the time of S/N characteristic evaluation and the signal loci on the phase plane. These charts indicate that noise during transportation, which becomes background noise on the phase surface, is of virtually the same phase as that of the defect signal. This suggests that (1) smooth transportation on the billet during defect detection is important, (2) there is a limit to the suppression of background noise by the phase detection and phase filter, and (3) realization of stabilized transportation and of a perfect profiling method for the probe unit along the billet are important. In the hot eddy current-testing device, roller vibration which is transmitted during transportation has been suppressed by providing pinch rollers front and rear as mentioned earlier. On the other hand, an air-servo system has been adopted as a profiling device; this system allows the probe unit to perform perfect profiling despite material vibration and a deformed shape.

The defect detection level for the eddy current testing device is determined for each steel grade as follows: Large, medium and small defect judgment levels are determined for each steel grade by O/C, and this determination is transmitted to the defect detector microcomputer via P/C. The defect detector receives signals from the transportation table, detects defects at a pitch of 50 mm in the lengthwise direction of the billet, and transmits defect detection results to P/C via a shift register. The P/C scans the defect status of all channels every 50 mm to compile a defect map of the billet. **Figure 14** shows an example of the displayed picture of defect detection results at the four sides and four corners, as outputted by P/C on a CRT screen. This defect information is the result of defect detection prior to VH rolling. After the billet is cut by the hot saw, tracking is performed of each piece of billet on its quality information.

3.5.3 Cold surface defect detection

Surface defect detection for cold billets is performed on all round billets as the final stage of quality assurance, with the following features:

(1) To detect hairine cracks (5 mm$L$ × 0.3 mm$D$) mainly consisting of scabs and longitudinal cracks,

Dimension		Measuring condition	
Ⓐ	$20l \times 2w \times 1.2d$	Frequency	: 32 kHz
Ⓑ	$20l \times 3w \times 1.5d$	Gain	: 17 dB
Ⓒ	$18l \times 3w \times 1.2d$	Channel	: No.15
Ⓓ	$22l \times 2w \times 2.5d$	High pass filter	: 15 Hz
Ⓔ	$15l \times 2w \times 1.1d$	Low pass filter	: 40 Hz
Ⓕ	$15l \times 2w \times 0.9d$	Speed of carriage	: 60 m/min
		Temperature	: 965 ℃

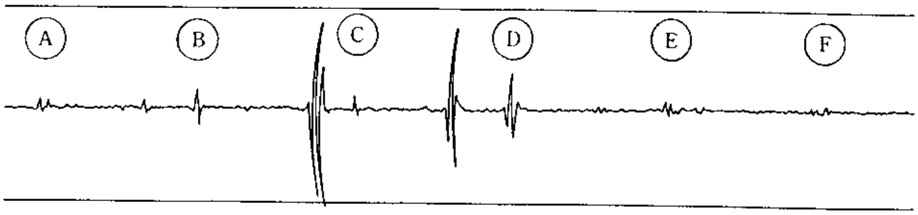
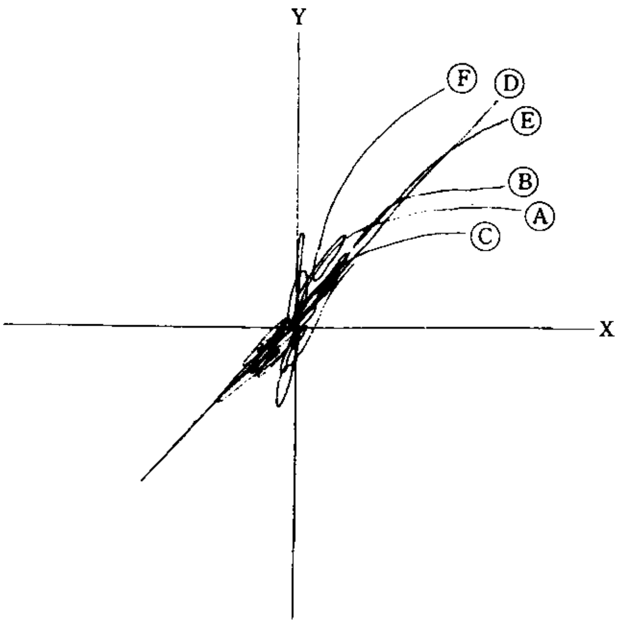


Fig. 12 Analog output of hot eddy current testing device (after phase detection)



Ⓐ~Ⓕ : Corresponding to Fig.12

Fig. 13 Analog output of hot eddy current testing device indicated on gaussian plane

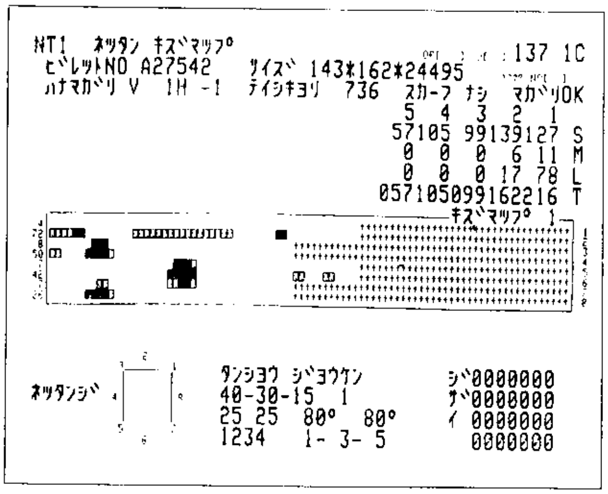


Fig. 14 CRT display of data from hot eddy current testing device

the detection tip is provided with Hall elements arranged in high density.

(2) An automatic conditioning system has been developed which has a sensor for defect detection and an actuator for grinding.

(3) To perform defect detection with all round billets to be processed at the finishing facilities, the defect detection speed has been incresed.

As defect detectors, an automatic magnetic defect detector of the leakage flux defect detecting type and a magnetic particle defect detector (following the surface-conditioning grinder) have been installed. Their specifications are shown in **Tables 5** and **6** respectively.

The front view of the automatic magnetic leakage flux testing device is shown in **Fig. 15**. It is of the gantry type and has two defect detecting units to improve its processing capacity. One unit is used as a standby in case of breakdown of the unit in use. As a billet is rotated in the circumferential direction on the turning roller while the defect detecting buggy transverses the billet surface, the detecting machine scans the billet surface in a spiral shape. Rotation of the turning roller is measured by PLG, and traversing speed is frequency-controlled. Further the end face portion is rotated in position,

Table 5 Specifications of defecting device by magnetic leakage flux tesing method

Item	specification
Detection method	Magnetic leakage flux testing method
Magnetizing method	AC magnetizing (3 kHz)
Detectability	0.3 mm(depth), 5 mm(length) for scabs and longitudinal cracks
Detecting device	Hall element
Distribution of device detecting	Pitch: 5 mm Number of device: 24 (on each head) Direction: longitudinal direction of billet
Detection coverage	120 mm/rev.
Rotating speed of turning roller	0.5 m/s-1.2 m/s
Capacity	80 000 t/month
Marking on defects	Three level (large, middle, small)

Table 6 Specifications of magnetic particle testing device

Item	Specifications
Method	Axis plod method Encircling coil method
Detectability	0.2 mm (depth), 5 mm (length) for scabs and longitudinal crack
Magnetization	6,000 A for axis plod method 10,000 AT (Ampere turn) for encircling coil method
Automatic position control of contacting rollers (electric poles)	4 steps due to diameter of billet

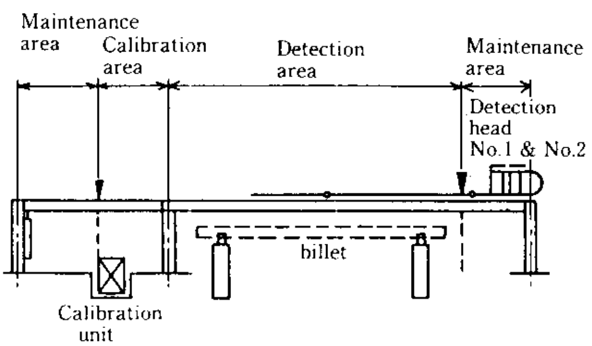


Fig. 15 Front view of magnetic leakage flux testing device

thereby permitting detection of the entire surface of the round billet. By forcing the detection head to follow the billet by using a guide, a peripheral speed of billet rotation amounts to 1.2 m/s at maximum, thereby making possible the monthly processing of 80 000 t. At the detection end, highly sensitive miniature Hall elements with a small temperature coefficient are arrayed to form 24 channels (for each unit) to detect hairline cracks. Differences in the sensitivity of elements caused by the use of multi-channel, are adjusted at the time of calibration. Sensitivity calibration is automated by using a signal processor incorporating an special-purpose microcomputer. As a result, the operator's work load has been reduced while the accuracy of the calibration work itself has improved.

The defect detection result is marked on defect itself, and the defect signal is transmitted to P/C where the "defect map" is compiled, indicating the depth of the defect (classified into "large," "medium" and "small") and its position, expressed in two dimensions. The example in **Photo 2** shows, on a single screen, half of the entire billet in the diameter direction (1 and 2) and a quarter in the lengthwise direction (A, B, C, and D). In drawing this defect map, a "reference mark" (a fluorescent paint mark measuring 3 mm$W$ x 200 mm$L$), which shows the standard position at every rotation of the billet, is applied to the top of billet to allow correction of positional errors arising from slipping or other causes. The position of reference mark is checked from the bottom side of the billet during defect detection. Using this reference mark to establish the orientation of the billet, the defect map is transmitted to the grinder in the next process and automatically controls grinding, determining the position and number of grinding passes. This constitutes a fully automatic conditioning system. In the marking operation defects are classified into "large," "medium", and "small," and distinguished by coloring. In order to mark the top of the billet, the response of the marking gun has been improved by use of a DC drive.

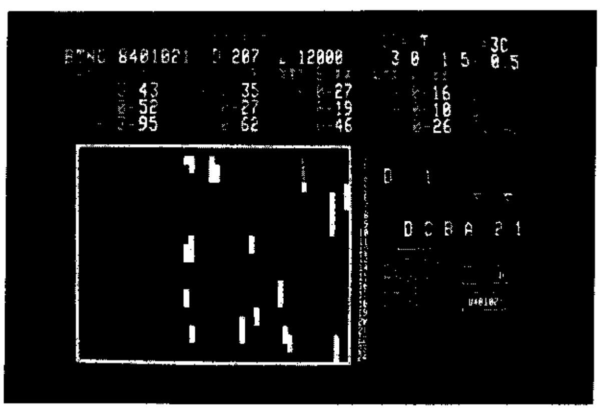


Photo 2 An example of defect map

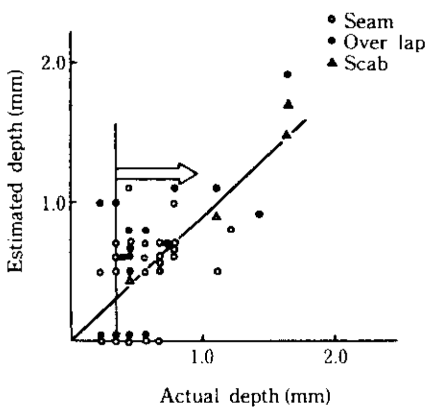


Fig. 16 Detecting capability of magnetic leakage flux testing device

By compensating for variations in diameter and rotational peripheral speed, an accuracy of ±5 mm has been achieved.

An example of the limits of the detection capacity of the magnetic leakage flux testing device is shown in **Fig. 16**. The scab and longitudinal cracking with a defect depth of 0.3 mm can be detected, in accordance with its original design specifications. The defect map produced by the device is stored in C/C, with information totalling 1 000 characters per billet.

4 Quality Records

4.1 Surface Quality

Table 7 shows a summary of the surface quality of round billets manufactured by the new billet mill in comparison with products of the wide flange beam mill. The table also lists the main points of surface quality improvements. With the billets manufactured by the new billet mill, defects due to rolling are rare, and those in high strength Nb- and V-bearing steels and caused in blooming have also decreased.

4.2 Defects Due to Bloom Surface Defects

The trend of occurrences of hairline cracks due to the difference in shapes of immersion nozzles is shown in **Fig. 17**. Changes in the inner diameter of the nozzle[6] have reduced the occurrence of the hairline cracks on the billet, which arise from blowhole defects in the bloom. This tendency is also applicable to defects 0.5 mm or greater in depth which appear in pipes after pipe-making.

Longitudinal cracks and scabs on the billet have also been reduced by increasing the inner diameter of the nozzle. This is attributable to the fact that discharge flow velocity of the immersion nozzle becomes slower and the depth of intrusion by the discharged flow becomes

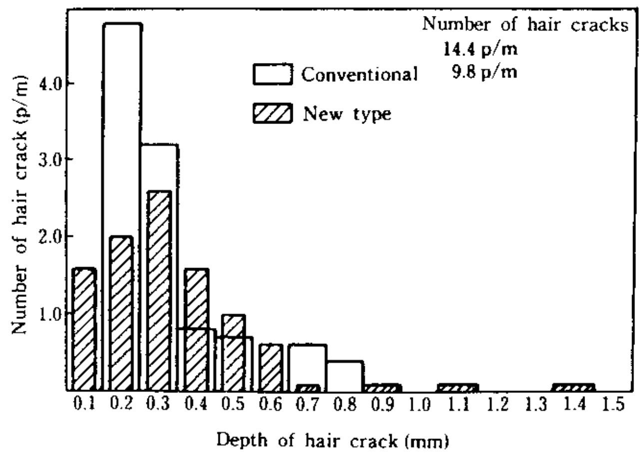


Fig. 17 Influence of immersion nozzle type on the distribution of depth of hair cracks

Table 7 Comparison of surface defect on round billets and content of quality improvement

Source	Surface defect	Billet mill	Wide flange beam mill	Improvement on billet mill
Surface defect of bloom	Longitudinal crack	No crack	Occurs on high tension steel	Improvement of immersion nozzle type in continuous casting
	Hair crack and scab	Average 10 number/billet	Average 14 number/billet	Improvement of immersion nozzle type in continuous casting
	Transverse crack	No crack with bloom of small cross section	Occurs on medium carbon, Nb content, or V content steel	Decrease of transverse crack by reduction of cross section area on bloom
Rolling	Scratch	No defect	Average 0.35 number/billet	Continuous rolling
	Over lap	No defect	Average 0.04 number/billet	
	Overfilled	No defect	Average 0.03 number/billet	

shallower, thereby reducing the occurrence of longitudinal cracks and slag inclusion of the bloom.

4.3 Rolling Defects

To prevent rolling defects, various measures have been taken at the new billet mill, some of which are given below.

(1) Use of roller guides to reduce the number of scratch defects which consist mainly guide scratches
(2) Execution of continuous rolling at the billet mill
(3) Adoption of shift transfer of the walking beam type

4.4 Round Billet Surface Nonconformance Index

As a result of preventing the occurrence of defects caused by bloom surface defects and rolling defects at the new billet mill, the index of nonconformance due to surface defects of round billets has decreased in comparison with that at the old billet mill, as shown in **Table 8**. After receiving and hot-charging blooms of excellent surface quality, billets can be rolled satisfactorily without hot scarfing, except in a certain steel grades.

Table 8 Comparison of surface defects of round billet between mills (investigation term Feb.-Jul., 1984)

Mill	Nonconformance index of round billet
Wide flange beam mill	60
Billet mill	6

4.5 Seamless Pipe Making Records

4.5.1 Surface conditioning index

Table 9 shows the difference in surface conditioning index between seamless pipes made at Chita Works from billets made by the new billet mill and those from wide flange beam mill at Mizushima Works. The surface conditioning index for pipe made from materials from the new billet mill has been drastically reduced. At the old billet mill, billets were conditioned, some after pickling and the rest after visual surface inspection. By contrast, however, at the new billet mill, all the billets are inspected and conditioned by the cold NDI devices and automatic grinding facilities.

Table 9 Conditioning index of surface defects of seamless pipe (investigation term Feb.-Jul., 1984)

Mill	Conditioning index of surface defect of pipe
Wide flange beam mill	100
Billet mill	48

4.5.2 Surface nonconformance index

Surface nonconformance indices of seamless pipes are shown in **Table 10**. Since the commissioning of the new billet mill, methods of inspecting and conditioning billet surfaces have been improved. Not only the surface nonconformance index but also the surface conditioning index has decreased.

Table 10 Nonconformance index of surface defects of seamless pipe (investigation term, Feb.-Jul., 1984)

Mill	Nonconformance index of surface defect of pipe
Wide flange beam mill	100
Billet mill	41

4.6 Quality of Square Billets for Bars and Wire Rods

Excellent surface quality of square billets has been obtained by the aforesaid measures for preventing material defects and rolling defects. These measures have also contributed to excellent surface quality of cold heading and cold forging steels, SC (carbon steel for machining use), alloy steels, and others.

Billets made at the new billet mill show less dispersion in their cut length and have advantages in full length uniform heating in the subsequent process (rod mill). The billets themselves also show less dispersion in sectional dimensions, thereby contributing to the manufacture of rods of high dimensional accuracy.

5 Conclusions

An outline has been presented of the quality assurance system of the new billet mill, which was constructed with the aim of realizing synchronized operation with the CC plant. The functions of quality assurance devices and results obtained have also been discussed. These newly-developed devices and the system as a whole have functioned smoothly in the trouble-free start-up of continuous operation between CC and rolling processes. Further, as can be seen in the decrease in the inner and outer surface defects in seamless pipes, the new billet mill can now provide high quality billets to the succeeding processes owing to the realization of high quality in products on the manufacturing line, high-accuracy detection of surface defects of blooms and billets, and development of mechanisms for conditioning and defect removal.

In the future, efforts will be made to enhance manufacturing techniques, improve facilities, and develop new techniques in order to achieve quality assurance at a still higher level. Effort will also be made to enhance quality in the wider sense, that is, in shortening processing time improving calculated-length ratio, and decreasing dispersions of dimensions and weight.

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