

Improvements of Billet Conditioning Processes

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Abstract

Steel billet quality is one of the important factors affecting the quality of bar and wire rod. In each Works of Nippon Steel Corporation, we have taken many measures to improve billet quality and quality control system. This paper introduces the following examples, (1) Improvement of billet conditioning processes in Muroran Works, (2) Automation of billet surface inspection in Kamaishi Works, (3) Construction of billet tracking system in Kimitsu Works.

1. Introduction

Inspection and conditioning of billets, the materials for rolling of steel bars and wire rods, play very decisive roles in the quality assurance of these products, because a small surface defect of a billet will be elongated during the rolling and becomes an extensive product defect, requiring a considerable cost for conditioning and making quality assurance in all the product length difficult. For this reason, steelmakers have taken measures to improve the defect detecting capability of their billet conditioning process, and to eliminate human sensory error in the inspection, mechanized and automated these processes.

Another important issue is that for the integrated quality assurance of steel bars and wire rods covering from steelmaking to the shipment of final products it is necessary to correctly track the process history of each billet. However, such tracking control requires much labor, and for this reason, the automation and computerization of quality control have been intensively pursued.

Nippon Steel Corporation has improved billet conditioning equipment and computer systems for quality control of its steel works aiming at enhancing the product quality of bars and wire rods as well as the overall performance of its quality control systems. This paper presents the following measures as examples of such improvement efforts:

- (1) Billet conditioning improvement measures at Muroran Works,
- (2) Automation of billet surface defect inspection facilities of Kamaishi Works, and
- (3) Construction of an individual billet control system at Kimitsu Works.

2. Billet Conditioning Improvement Measures at Muroran Works

2.1 Background situation

A considerable percentage of steel bars and wire rods is used for safety-related parts of automobiles after undergoing post-processing steps (secondary and ternary working). Quality requirements for these steel products are becoming increasingly diversified in consideration of the workability at the secondary and ternary working and the use conditions of the machine parts into which they are made. In addition, the need for quality assurance throughout the entire length of the steel products has also increased, and the steelmakers are required to apply very severe quality standards¹⁾.

In such a situation, the importance of the reliability of inspection and conditioning of billets has increased significantly. In addition, appropriate feedback of billet inspection results to the billet production processes (continuous casting of blooms and billet rolling from blooms) is effective for improving the quality of billets and the final products.

In consideration of the above, Muroran Works decided to inspect all the surfaces of every billet twice, improve the traceability of the inspection and conditioning information of billets to final bars and wire rods, and promptly inspect and condition all the billets of one converter charge as one lot so that the billet inspection results could be fed back to the continuous casting and bloom rolling processes quickly. For these ends, a new inspection and conditioning line for special steel billets, having a processing capacity twice that by the conventional processes, was constructed immediately downstream to the billet rolling line in December 2002, and at the same time, a computerized system for improving billet quality based on feedback

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of billet inspection information was established. This paper outlines the newly introduced equipment and quality information system.

2.2 Layout of billet inspection and conditioning line

Fig. 1 compares the process flow of the billet inspection and conditioning at Muroran Works before and after the commissioning of the new line. By the old process flow, after the UST, each billet went through one pass of a surface inspection line with a manually operated magnaflux flow detector. Since the inspection depended on the sensory capability of operators, it was necessary to process the billets for products subject to stringent quality standards twice through the line.

Fig. 2 shows the layout of the new automatic billet inspection and conditioning line. First, billets from the UST undergo the first surface inspection by automatic magnaflux flow detectors; thanks to the fully mechanized inspection, the inspection accuracy and productivity improved significantly and it became possible to store the inspection results electronically in the form of flaw image data. The automatic magnaflux flow detectors feed flaw position information to the automatic conditioning machines to make the first inspection/conditioning sequence fully automatic. To detect and remove deep defects that remain after the automatic surface conditioning, manual magnaflux flow detectors are provided as the second inspection step. The defects detected at this stage are removed with manual grinders on specially designated, in-line tables.

2.3 Outline of new inspection and conditioning equipment

2.3.1 Automatic magnaflux flow detector

Table 1 shows the main specifications of the magnaflux flow detector, and **Fig. 3** schematically illustrates the new equipment. This

equipment, which was developed in-house, uses a ring coil and two yoke coils, and by virtue of this combined magnetization method, it can detect either a longitudinal or transversal surface defect. One flaw detector inspects two of four surfaces of a billet, and after turning the billet by 180 degrees, a second flaw detector inspects the other two surfaces; this sequence minimizes the flow of excessive magnetic particle liquid to prevent disturbance. The combination of a high-luminosity ultra-violet lamp and a high-resolution CCD camera makes it possible to detect defects 5 mm in length or more, half the size that the conventional practice could detect.

2.3.2 Automatic defect conditioning equipment

Table 2 shows the main specifications of the automatic defect conditioning equipment, which is schematically illustrated in **Fig. 4**²⁾. To obtain mirror-finish surfaces to improve the flaw detection accuracy at the second inspection, milling cutters are used for removing the defects. **Photo 1** compares the surfaces machined by a milling cutter and a grinder.

Table 1 Main specifications of automatic magnaflux flow detector

Inspection speed	30 m/min
Detectability	Seam: depth 0.3 mm, length 5 mm Scab: depth 0.3 mm, length 5 mm
Magnetization	One ring coil and two yoke coils
Camera detector	Three CCD cameras per one billet surface
Data processing system	Parallel processing by several general-purpose computers

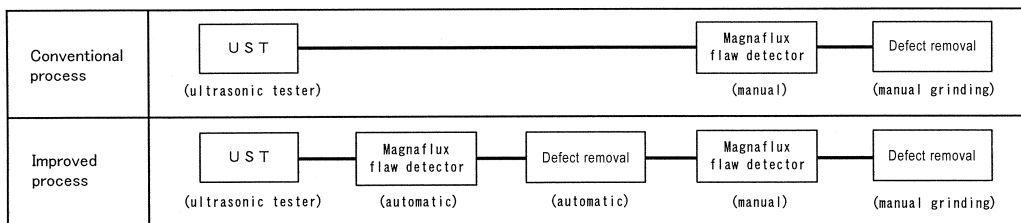


Fig. 1 Billet conditioning processes

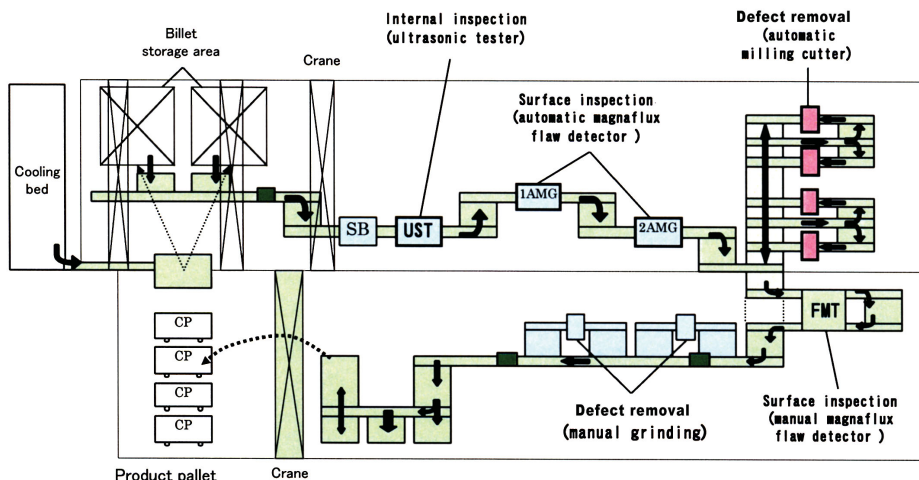


Fig. 2 Automatic billet conditioning line layout (new process)

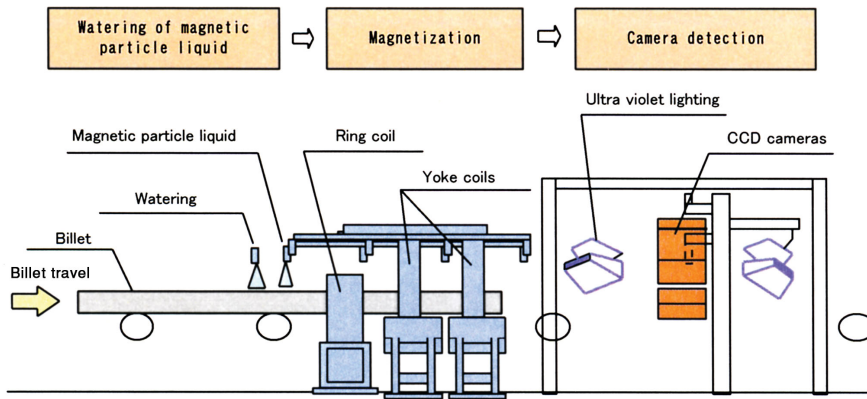


Fig. 3 Schematic illustration of automatic magnaflux flaw detector

Table 2 Main specifications of automatic milling cutter

Cutting method	Milling cut method of two surfaces at the same time
Cutting depth	Depth: 1.0 - 3.0 mm
Cutting control	Longitudinal way: Hydraulic driven motor, measuring by PLG
	Transverse direction: AC servomotor
	Depth direction: AC servomotor, measuring by automatic sensor
Cutting type	Staggered split chip type

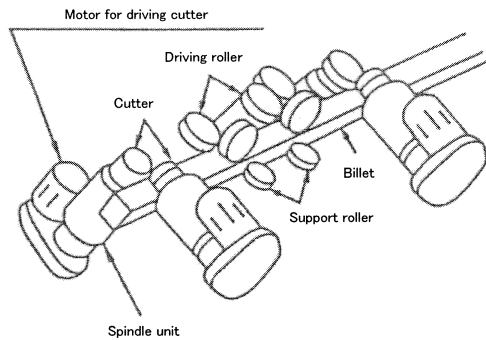


Fig. 4 Equipment outline of automatic milling cutter

2.4 Whole lot inspection of billets immediately after casting and rolling

Fig. 5 compares the production processes of special steel bars and wire rods before and after the improvement, covering from steelmaking to shipment of the final products to customers, and Fig. 6 some aspects of billet quality control likewise. The time from tapping of steel from a converter to the inspection completion of all the billets cast from the batch of steel was very long (30 days in average) before the improvement, and it was difficult to correlate the inspection results of billets with the smelting and casting conditions of the steel from which they were produced. In addition, since the billet inspection records were prepared manually by inspectors as seen in the lower left frame of Fig. 6, it was difficult to accurately describe the defect shape and position and calculate their occurrence rate. Furthermore, billets were usually stored after their rolling without being inspected, and inspected only when they were allotted to a specific order, and for this reason, if more billets were rejected at the inspection than initially expected, it was necessary to bring supplementary billets for the order from the stockpile.

After the commissioning of the new inspection and conditioning facilities, a system was instituted whereby all the billets cast and rolled from a charge of steel were inspected immediately after their rolling. As a result, the feedback time of billet quality information to the steelmaking, casting and rolling processes was shortened from 30 days in average to only two days. In addition, as stated earlier, it became possible to store flaw image data electronically and record the positions and frequency of defect occurrence quantitatively. Based on this, a new quality control system utilizing the LAN of the Works was established, which enabled the quality control and production organizations to quickly retrieve the information and analyze the

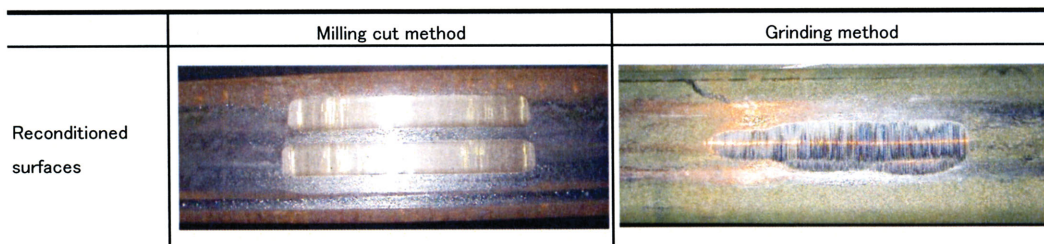


Photo 1 Comparison of reconditioned surfaces between milling cut method and grinding method

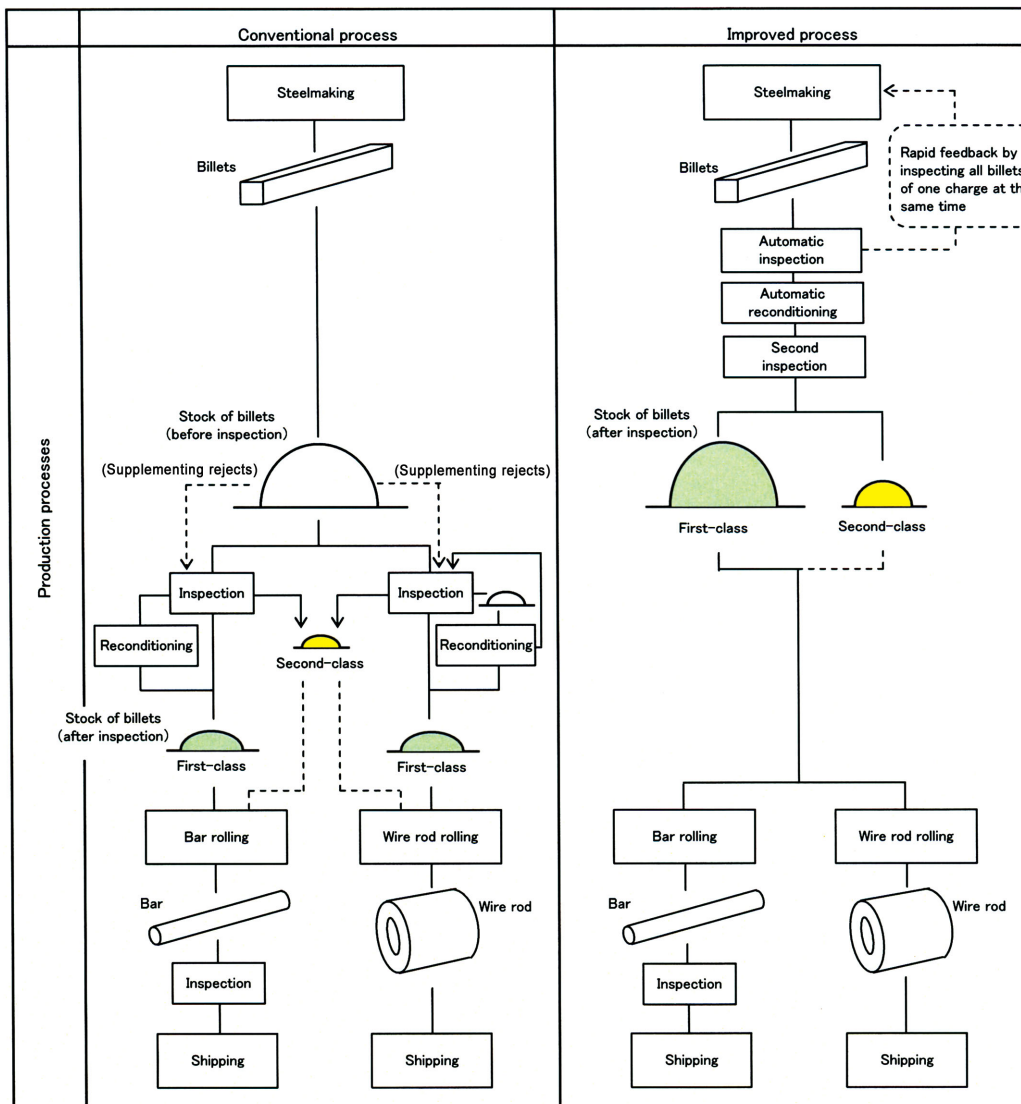


Fig. 5 Special steel bar and wire production processes

trend. In working out the new quality control system, emphasis was placed on the traceability of the quality data of final bars and wire rods back to the inspection and conditioning results of individual billets. Now, the flaw image data are stored for three years to make it possible to correlate the performance information of products during the post-processing at customers with their quality information along the production processes. After the establishment of the new system of 100% billet inspection immediately after their casting and rolling, every billet stocked in the storage yard came to have an inspection record, and as a result, the scheduling and materials flow of the billet rolling and downstream processes became stable.

Fig. 7 shows the change in the flaw area ratio before and after the above improvement measures; here, the flaw area ratio is defined as the ratio of the number of 5-mm-square areas (25 mm² each) that contain surface defects to the total number of the 5-mm-square areas of all the four surfaces of a billet. Thanks to the 100% billet inspection system, the P-D-C-A cycle of the quality control of billets began to work more effectively, improving billet production processes and

lowering the flaw area ratio significantly.

2.5 End remarks

As a result of the improvement measures presented above, the reliability of the billet inspection and conditioning work as well as the billet quality forming at the steelmaking, continuous casting and billet rolling processes improved dramatically. The new billet control method introduced at the time of the commissioning of the new equipment offers a firm basis for further enhancing billet quality and inspection accuracy to meet quality requirements of customers, which are becoming increasingly sophisticated year by year.

3. Automation of Billet Surface Defect Inspection Facilities of Kamaishi Works

3.1 Background situation

At Kamaishi Works, the inspection of surface defects of billets was done by the magnetic particle examination with billets traveling on a roller transfer table, but since the inspection depended on the sensory capability of inspectors, the detection accuracy was not stable,

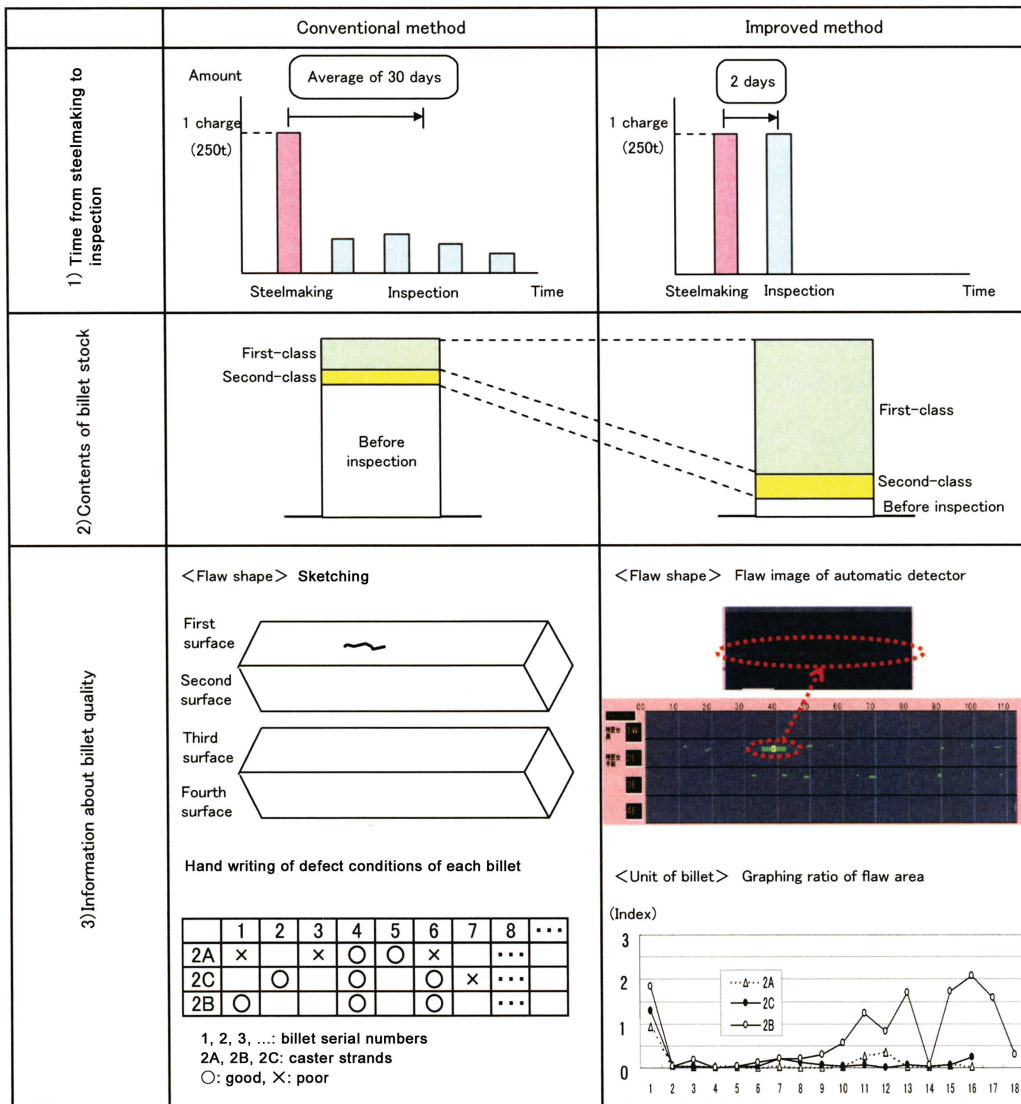


Fig. 6 Quality improvement methods

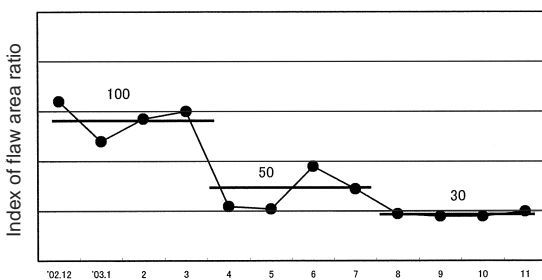


Fig. 7 Trend of flaw area ratio

and sometimes problems such as overlooking a defect, excessively severe inspection and conditioning of acceptable defects occurred. In view of this, to improve the defect detection accuracy and labor productivity, the surface defect inspection equipment was revamped in September 1999.

3.2 Outline of inspection equipment

Fig. 8 is a schematic elevation view of the automatic magnetographs newly introduced for the inspection of surface defects of billets, and Fig. 9 shows the defect detecting unit of the magnetograph. The magnetograph uses the defect detection method by magnetic recording for the first time in Japan. The processes of defect detection are as follows.

- (1) A yoke coil magnetizes a billet traveling on a roller table at a constant speed.
- (2) If there is a defect at a surface of a billet, a leakage flux occurs there, which is recorded using a rubber magnetic tape pressed onto the surface.
- (3) To inspect all the four surfaces of a billet without having to rotate it, there are two inspection stations, each having two detecting heads for two opposing billet surfaces, the detecting heads of one station being arranged at right angles to those of the other station.
- (4) A scanner reads out the defect signals recorded in a rubber

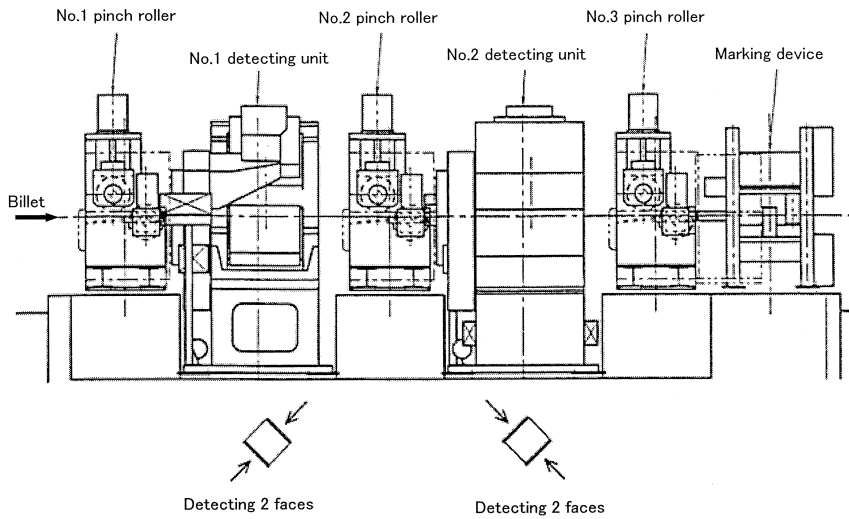


Fig. 8 Equipment outline of automatic magnetograph

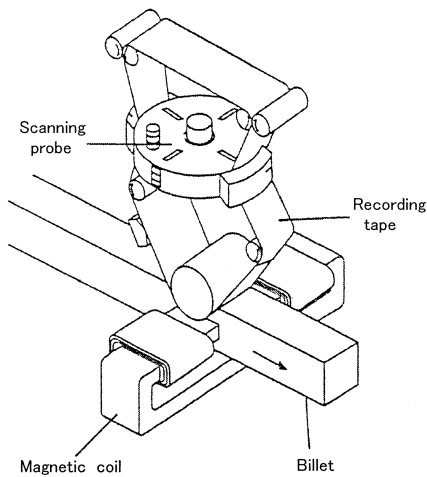


Fig. 9 Construction of detecting unit

magnetic tape, and through signal processing, the position of a defect exceeding a prescribed degree of severity is determined and marked with paint using a spray gun.

3.2.1 Equipment characteristics

The characteristics of the surface defect detecting equipment are as follows:

(1) Quantification of defect depth

The magnetic recording method makes it possible to accurately judge defect depth. Fig. 10 shows the relationship between recorded signals and defect depth. As the graph shows, defect depth is substantially proportional to signal strength up to a certain depth, and it is possible to estimate defect depth from signal strength. The accurate judgment of defect depth significantly improved the reliability of defect detection, and as a result, overlooking of harmful defects and over detection of acceptable defects decreased remarkably.

(2) High reproducibility of inspection results

With this method, the leakage flux at a surface of a billet is directly recorded in a magnetic tape, and the recording is little affected by disturbances; as a result, this method reproduces defects at a higher reliability than by other methods.

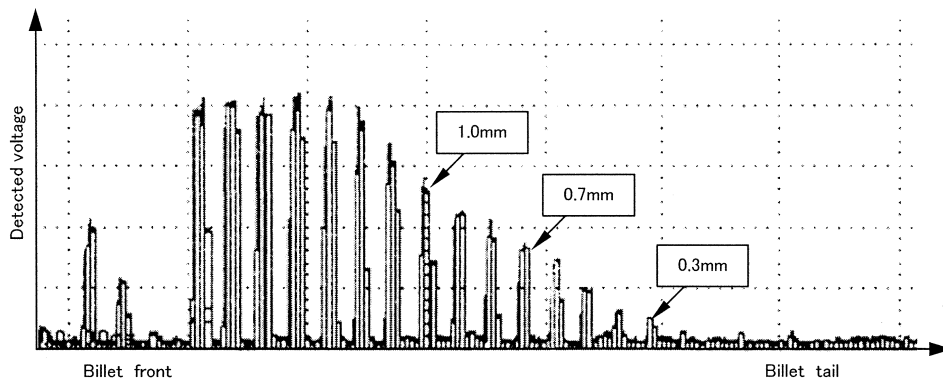


Fig. 10 Detecting result by depth of defects

(3) Classification of defects by the type

There are various types of surface defects such as a crack, scab, etc., and the criterion for judging whether a defect is harmful is different depending on the type of defect. Kamaishi Works worked out logic to define the type of defect from its width and continuity and individually judge the harmfulness of a defect in consideration of the type.

(4) High inspection speed

The magnetic recording method allows an inspection speed about 1.5 to 2.0 times that of conventional visual inspection. Thus, in addition to the labor saving through automation, a significant improvement in labor productivity was achieved.

3.2.2 Initial problems and countermeasures

While the defect detecting system using the magnetic recording method showed the advantages described above, there were problems in relation to things such as poor detection of defects at billet corners and short life of the magnetic tape, and for these reasons, all the defect detecting systems by the same method introduced to overseas plants are not operative now. With help of the equipment builder, Kamaishi Works introduced a variety of measures to improve the equipment and the quality of the magnetic tape, and presently, the system has been functioning satisfactorily and continuously for a long period. The principal measures taken to overcome the problems are described below.

(1) Improvement in defect detection at billet corners

Because the magnetic tape did not contact well the corners of a billet, it did not catch defect signals perfectly in those portions. What is more, noise arose from places such as the boundaries between portions contacting the tape and not contacting it, and the S/N ratio was markedly worse at the corners than at the flat surfaces. Soft rollers of a foamed material to press the magnetic tape onto the corners made it possible to detect defects along the entire contour. In addition, as a countermeasure against the fluctuating pressure of the soft rollers due to bending of billets or some other cause, guide rollers contacting the billet surfaces were provided to keep the tape-pressing force constant. As a result, it became possible to detect defects in all the billet surfaces accurately and stably.

(2) Improvement in magnetic tape life

(i) Synchronization of billet traveling speed and tape speed

The construction of the inspection station was such that billets were transferred on V rollers. Although the V rollers were driven at a constant speed, billets were found to travel at widely changing speeds depending on the position of billet/roller contact and the wear of the rollers. Therefore, even when the speed of the magnetic tape was set at that of billet travel, it would not synchronize with the actual travel of billets, leading to friction between them and premature wear of the tape. To prevent this, a system was devised to measure the billet traveling speed continuously and control the tape speed in perfect synchronization. The system proved effective and the life of the magnetic tape improved remarkably.

(ii) Selection of optimum tape thickness

Making the magnetic tape thicker to increase its strength was expected to be effective in extending its life, but defect signals were found to deteriorate as the tape thickness increased. In consideration of this, tapes of different thicknesses were tested to define the critical tape thickness not to fail to detect harmful defects, and a tape about 1.5 times thicker than the original one was finally selected.

(iii) Effects

Thanks to the measures (i) and (ii) together with other minor modifications, the life of the magnetic tape increased to five times

the initial tape life, realizing a significant decrease in the operation costs.

3.3 End remarks

The automation of the inspection of billet surface defects led to a significant improvement in defect detection performance and decrease in the inspection costs. It is expected that the defect position data obtained through the new method are effectively utilized for things such as automation of surface conditioning work. Such improvement efforts will lead to a more reliable quality assurance system and manufacturing of products worthy of customers' trust.

4. Construction of Individual Billet Control System at Kimitsu Works

4.1 Background situation

The billet production plant of Kimitsu Works produces not only billets for the Wire Rod Mill of the same Works but also those for the Wire Rod Mill Plant of Kamaishi Works and for outside the company. For this reason, the billet conditioning line of the plant handles quite a large number of billets of widely different steel grades and standards, and therefore, reliable billet identification, efficient materials handling and storage have always been the important tasks for the people working there. In addition, increasingly stringent quality requirements came to be applied to wire rod products from the late 1980s, and accordingly, it became necessary to control product quality by vertically tracking the history of each billet through all process steps, but such a quality control practice inevitably required heavy labor input.

After the development and introduction of a stamper and readers of billet identification numbers in the early 1990s, Kimitsu Works has actively automated and mechanized the billet conditioning work, improved the method for identifying individual billets, and established an integrated tracking system based on information exchange between the steelmaking, billet rolling, conditioning, and wire rod rolling processes. The following sub-sections present these improvement measures.

4.2 Introduction of a billet stamper and automatic number readers

4.2.1 Background

Fig. 11 schematically shows the layout of the billet rolling and conditioning line of Kimitsu Works. Quality control based on identification of individual steel material following the complicated process flow inevitably required a great amount of labor, and yet the reliability of the billet identification was far from being perfect. For this reason, the material identification in the billet conditioning process was limited to the identification of a group of billets cast from one converter charge except for special cases. As a consequence, the billet inspection and conditioning process constituted a problem in constructing an individual and integrated tracking system covering from the steelmaking to wire rod rolling processes.

4.2.2 Outline of improvement measures

A stamper for marking a billet number and automatic readers of the stamped number were introduced in April 1991 to control the billets for wire rods individually. The outlines of the equipment are as follows.

After the rolling of blooms through the billet mill and cutting to length, the stamper shown in **Fig. 12** would stamp a billet identification number comprising eight digits at an end face of each billet in hot; for the identification number to survive the tough conditions at the downstream processes such as shot blasting and magnaflux inspection, the stamping method was selected instead of

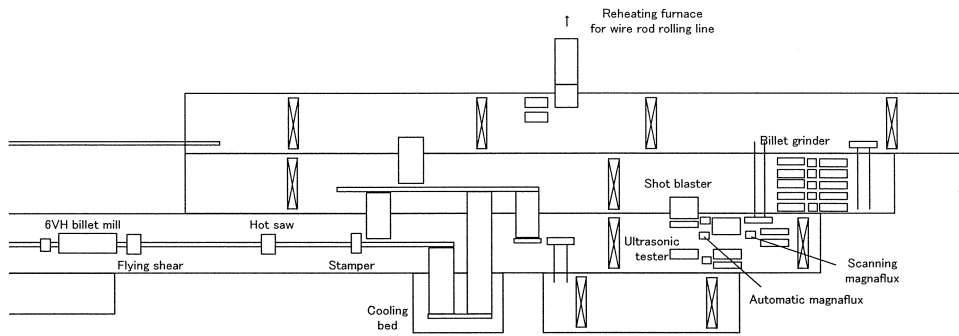


Fig. 11 Layout of billet rolling and conditioning line

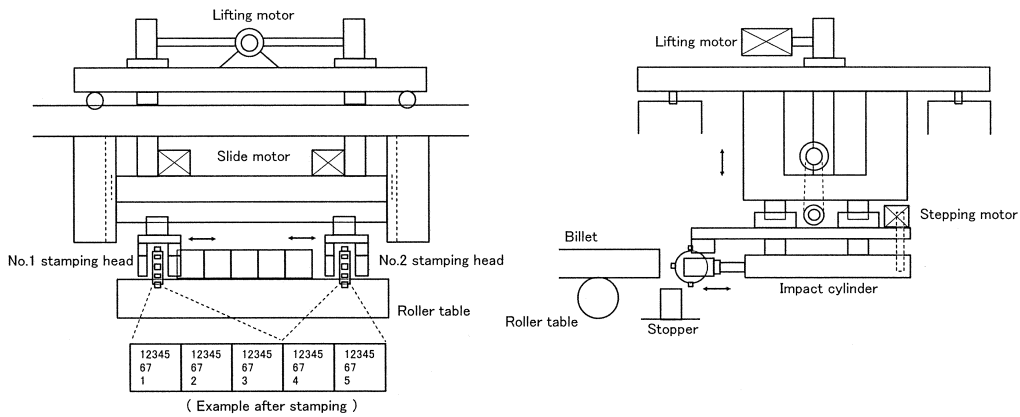


Fig. 12 Billet stamper

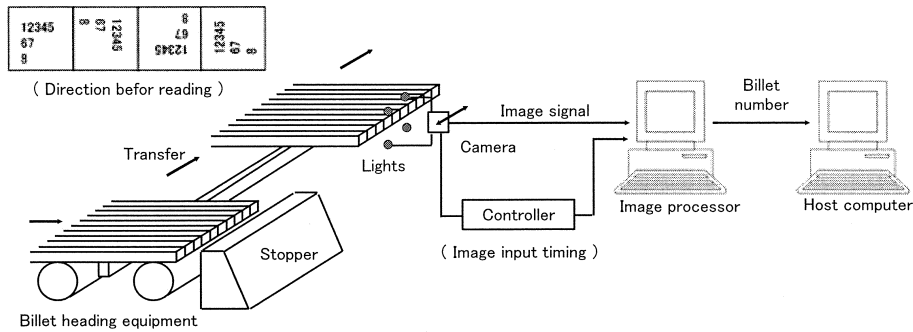


Fig. 13 Reading system diagram

attaching a heat-resistant label or the like.

An automatic mark reader was provided at the entry to the billet conditioning process, namely at the front of the magnaflux detectors, as shown in Fig. 13, to read the identification number of each billet after shot blasting to confirm its sequential order in the magnaflux inspection. This information is used also for tracking the processing at the subsequent ultrasonic testing and grinding. Another automatic mark reader was installed at the entry to the reheating furnace of the wire rod rolling line to confirm the furnace charging sequence of individual billets for the tracking control at the wire rod rolling.

These facilities enabled the tracking of individual quality information throughout the sequential processes from billet rolling to wire rod rolling. Later, a paint marker of bloom numbers was provided at the exit from the bloom caster and a bloom number reader at the entry to the rolling line to roll blooms into billets, and this made it possible to input the quality information of individual blooms, which had been done manually, to the individual tracking system electronically. More recently, another individual tracking system was introduced to the stock yard for finished wire rod products, and thus a through-process tracking system for quality information of

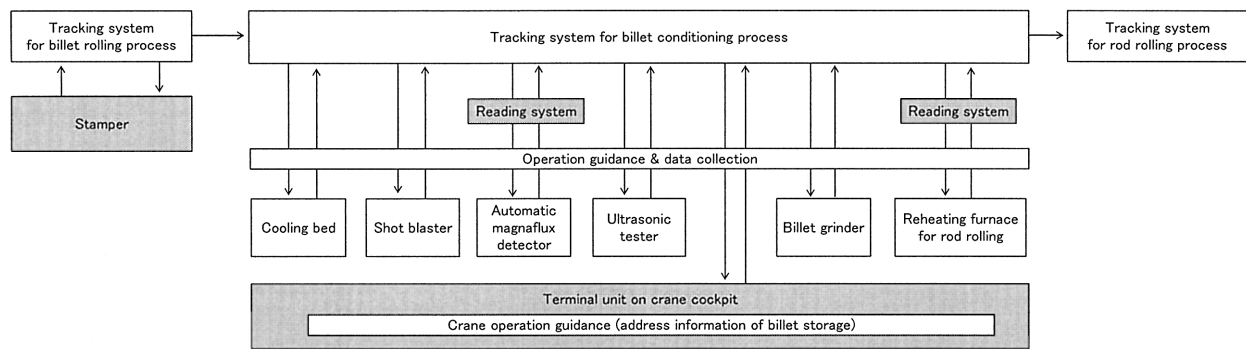


Fig. 14 Diagram of tracking system for billet conditioning line

individual steel materials covering from steelmaking/bloom casting through billet rolling, billet conditioning and wire rod rolling to wire rod shipment was completed.

4.3 Control of billets in storage yard

4.3.1 Background

The individual tracking system for billets inside the billet inspection and conditioning yard was established with the introduction of the billet number stamper and number readers. However, even after their introduction, the allocation of storage areas inside the billet yard was done based on the charge number of the converters as was the case conventionally, and for this reason, any one billet was not identifiable in the tracking system until its number was read by a number reader on an occasion of inspection or conditioning. As a result, identification of individual billets in storage areas had to depend still on visual recognition, and thus, a labor-intensive and inefficient way of working remained.

4.3.2 Outline of improved tracking system

To automate the storage control of individual billets in the billet conditioning yard, a billet tracking system using a business computer was established in December 1993 and applied to billets on the cooling bed, which was the initial point of individual billet identification, and to utilize the information of the tracking system for the billet control at the storage yard, each of overhead traveling cranes was provided with an input terminal. Note here that billets are handled and piled in a row in the storage yard by a unit of 10, and the position of each billet in the unit row is input to the tracking system. The functions of the new tracking system are outlined below.

At the time of billet acceptance to the storage yard immediately after rolling and cooling, the numbers of the billets and their storage yard address are input through the crane terminal for the tracking of individual billet information. Conventionally, these pieces of information lacked, and it was necessary for personnel on the billet yard floor to confirm the numbers and positions of the billets and give signs to the crane operator. Another function of the individual tracking system is to automatically classify billets based on the information of their magnaflux inspection results and addresses in the storage yard. To maintain high accuracy of the tracking system in identifying billets, a position detector using radio guidance was provided to each crane terminal, an ITV camera was installed at each of inspection and conditioning facilities as back-up for billet identification with a monitor provided at each operator room.

As a result of these measures, an integrated, fully automatic system

for continuously tracking individual semi-finished and finished products covering from steelmaking through bloom casting, billet rolling, conditioning and wire rod rolling to product shipment was completed. Fig. 14 schematically shows the structure of the tracking system within the billet conditioning processes.

4.4 Additional measures

Kimitsu Works has also pursued a method for effectively utilizing the inspection and quality information obtained through the billet conditioning processes. Automatic magnaflux inspection equipment similar to that of Muroran Works was introduced in 1997, and a system was established for automatic defect detection and marking as well as inspection standard control (adequately setting the detection sensitivity of the inspecting facilities according to applicable standards) and input of inspection results to the business computer system by effectively utilizing the billet number readers. The new system was later expanded to cover the standards and results of ultrasonic inspection, and automatically control the quality information of each billet based on the billet grinder operation information for each billet.

4.5 End remarks

This Section has presented the latest individualized billet control system of Kimitsu Works based on tracking of process and quality history of each billet. Billet conditioning is the final process the performance of which determines the quality of the final wire rod products in the whole length, and in this sense, the establishment of the tracking system of the quality information of individual billets and automatic control of the information is very significant. The system is expected to be instrumental in further enhancing the quality level of the wire rod products and earning trust of customers.

5. Closing

This article has presented some examples of equipment and system improvements in the field of billet inspection and conditioning. Nippon Steel continues to bend efforts to further enhance quality control and quality assurance systems in response to increasingly stringent customer requirements for quality improvement.

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