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Automatic Defect-Detector with Scarfer for Slabs

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Abstract:

Nippon Steel manufactures many types of high-grade products, including hot-dip galvanized steel and high-strength steel. Nagoya Works is a large production base for sheet products with severe quality requirements to meet, such as automotive outer panels. This plant was engaged in the development of an automatic check scarfing unit capable of detecting subsurface inclusions in slabs for the purposes of quality control and quality production in the slab stage. Focusing on the fact that subsurface inclusions produce sparks when the slab is scarfed. This development made good use of scarfing technology to generate bright inclusion sparks without adverse effect on slabs in the next process and of signal processing technology to count minute sparks in real time. Nagoya Works commercialized the first automatic slab check scarfer that fully automatically checks hot slabs for quality as was desired for many years in the steel industry.

1. Introduction

Nippon Steel builds desired quality into quality-critical steel sheet products, as represented by automotive outer panels, by integrated manufacture and control with respect to nonmetallic inclusions. These inclusions lead to surface defects and press forming cracks among other imperfections. These inclusions are mainly present just below the surface of slabs and have long been known to appear as sparks when the slab is scarfed. Hand check scarfing is a slab quality judgment method that takes advantage of this physical phenomenon. Formerly, the inspector allowed a hot slab to cool to room temperature, and then hand scarfed the cold slab and judged the quality of the slab by visually observing the sparks produced by the inclusions contained in the slab. This slab quality judgment by scarfing was a punishing duty that could be performed only by a skilled worker who directly and manually operated a very hot scarfing nozzle on each slab and visually observed the sparks from the molten pool formed in the slab.

The automation of this hot slab quality judgment was strongly demanded to increase the direct hot charge rolling rate of slabs and condition all slabs in an optimum manner. Work was started on the development of an automatic check scarfer to make an on-line quality judgment on hot slabs transported from a continuous caster to a hot strip mill reheating furnace by counting the sparks generated by the subsurface inclusions present in the hot slabs. Both quality assurance and yield improvement is thereby accomplished.

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2. Background to Development of Automatic Slab Check Scarfing Technology

The establishment of automatic slab check scarfing technology absolutely called for mechanization and automation technology and high-speed image processing technology. The mechanization and automation technology was required to obtain clearly visible sparks and to scarf slabs in such a way that the scarfing track would be smooth enough to have no adverse effects on the slabs in the subsequent processes. The high-speed image processing technology was required to immediately and continuously process the generated sparks. The objective was the embodiment of an automatic scarfing machine with vision and intelligence. The problems of the check scarfing technology are shown in **Fig. 1**.

To overcome these problems Nagoya Works started basic research and development in April 1987. Concerning scarfing, Nagoya Works tests made various scarfer nozzles jointly with NIPPON SPENG CO., LTD., a hot scarfer manufacturer, and established optimum scarfing conditions after persistent scarfing tests. In September 1988 a test apparatus was installed and used on a large tonnage of slabs. The results of this on-line testing showed it possible to establish necessary spark counting and image processing technology. The establishment of this technology was due to the increasing penetration and versatility of image processing technology and to the increasing capacity of microprocessors. In February 1989 Nagoya Works completed the development of the automatic slab check scarfing technology and grasped the factors involved. The study of a commercial machine and system immediately followed. In August 1989 the modification of the No. 2 reheating furnace was started and the automatic slab check scarfer at the hot strip mill was installed. After many improvements the automatic check scarfer was successfully put into regular operation in April 1992.

3. Development of Automatic Slab Check Scarfing Technology

3.1 Targets of technology development

The development targets of the automatic slab check scarfing technology were set as follows:

(1) Smooth scarfing track that does not adversely affect the slab in the next process,

(2) Spark counting accuracy comparable to that of visual quality judgment,

(3) Highly reliable equipment with an availability of over 95%.

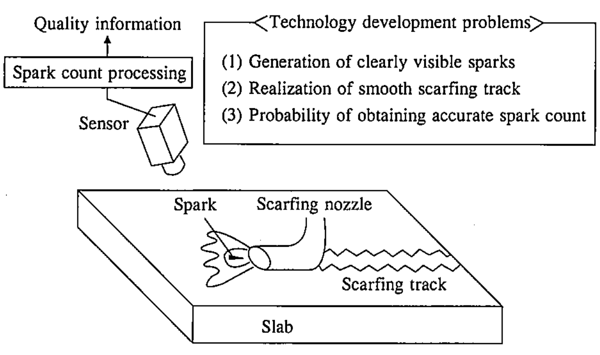


Fig. 1 Problems of check scarfing technology

3.2 Establishment of spark detection scarfing conditions

Fig. 2 shows the conditions of the molten pool and sparks when a slab is scarfed. To use check scarfing as a means for quality inspection, such a molten pool must be formed that sparks as objects of inspection can be distinguished from oscillation sparks as disturbances. Since the oscillation sparks are produced at the leading edge of scarfing, the inclusions can be easily distinguished from the oscillations according to the spark positions, if an oval molten pool is formed in the scarfing direction. Hot scarfing testing was conducted using various shapes of scarfing nozzles. The test results showed that a nozzle with round oxygen holes conventionally used for hand scarfing, produced an oval molten pool, making it possible to distinguish the oscillation sparks from the inclusion-derived sparks.

Next, the optimum scarfing depth and the factors that govern the scarfing depth are discussed. Many inclusions are distributed at 2 to 3 mm below the surface of slabs. In automatic check scarfing to detect these subsurface inclusions in the slabs, it is necessary to control the scarfing depth at a constant level.

Scarfing itself is an oxidation reaction. The scarfing depth changes with the scarfing speed and slab temperature as shown in **Fig. 3**. The scarfing depth was held constant by controlling the scarfing speed while taking the slab temperature as a parameter as shown enclosed with an oval frame in **Fig. 3**.

Another factor that greatly affects scarfing is the oxygen flow rate (or oxygen pressure). When the oxygen pressure is too low, the molten pool is not formed as a long oval one. When the oxygen pressure is too high, the spark generation time becomes extremely short. In either case sparks are not readily generated from microscopic inclusions. Spark images were observed with a video camera and monitor television. The optimum oxygen pressure was consequently set at 0.45 kg/cm^2.

Based on the above-mentioned automatic scarfing conditions, the slab temperature was investigated for its effect on spark emissions. Conventional quality inspection by hand scarfing was performed only on cold slabs. It was necessary to check that an equivalent spark quantity was obtainable with hot slabs as well. Nine slabs were prepared. The number of sparks generated by the auto-

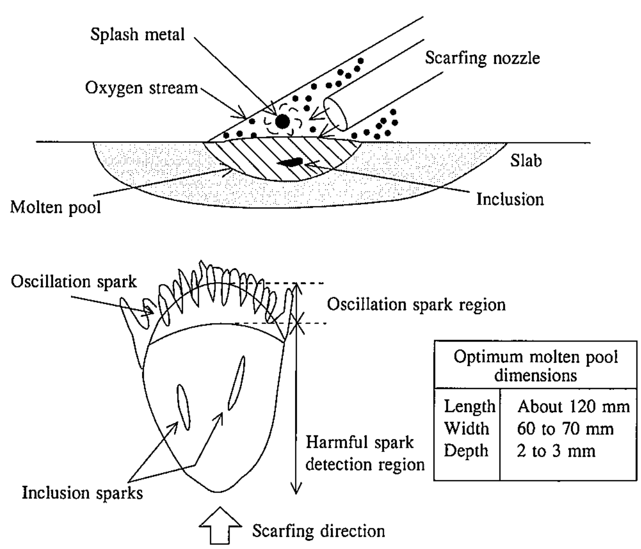


Fig. 2 Scarfing conditions

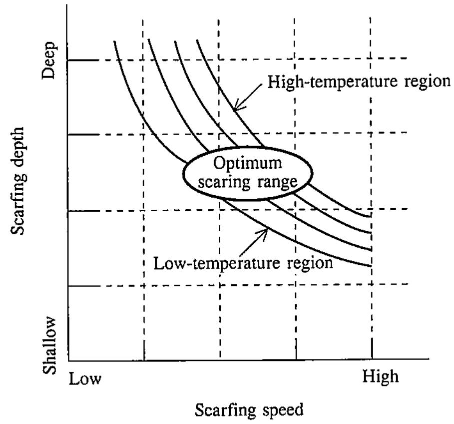


Fig. 3 Scarfing speed and depth

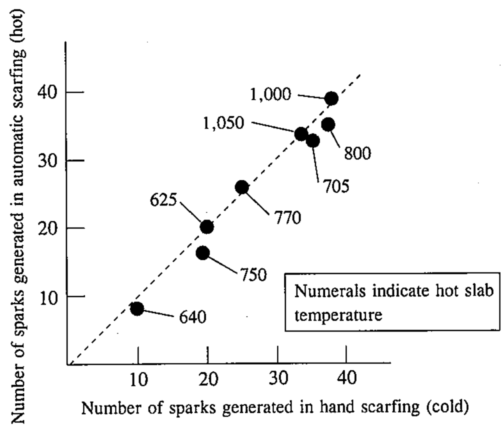


Fig. 4 Effect of slab temperature on number of sparks generated

matic scarfing of hot slabs was compared with the number of sparks generated by the hand scarfing of cold slabs. The results are shown in **Fig. 4**. It was verified that the number of sparks generated does not change with the slab temperature and that spark detection can be performed at the same level over the slab temperature range investigated.

3.3 Development of fin-free scarfing technology

When the slab is scarfed, the molten metal is scattered by the kinetic energy of scarfing oxygen out of the oxidation reaction range and is left as fins. These fins remain as harmful scabs when the slab is rolled in the next process. The technology of eliminating the residual fins was developed. The results of scarfing with different nozzles are shown in **Fig. 5**.

The round nozzle used in hand scarfing excels in spark detection as already described, but leaves fins at both sides of the scarfing track. There is a slit nozzle that eliminates fins by blowing air to both sides of the scarfing track and melting the roots of fins. When the slit nozzle was used, however, the molten pool was short in the scarfing direction, and no sparks were generated. A compound nozzle was developed by positioning a round scarfing oxygen hole at the center, providing a fin-preventing slit groove on each side of the scarfing oxygen hole, and attaching a lower unit tapered on both sides. The compound nozzle succeeded in generating sparks without leaving fins at the sides of the scarfing track.

3.4 Principle of scarfing spark emission

The scarfing spark image and cross-sectional light quantity distribution produced by the check scarfer as described above are shown in **Fig. 6**. The cross-sectional light quantity distribution revealed no peaks at specific wavelengths. Scarfing sparks did not change when holes were drilled in the slab surface or when cement, aluminum, and brick were inserted into the drilled holes. The principle of scarfing spark emission may be considered as follows. When the flow of molten metal is obstructed, some of the molten metal is splashed into air and instantaneously oxidized by the high-pressure oxygen gas to emit intense light.

Inclusion-derived sparks are characteristic in that:

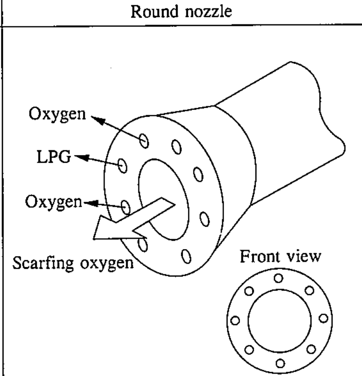
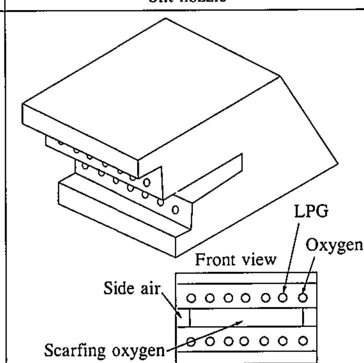
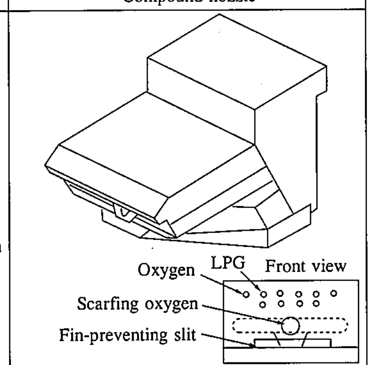
Item	Round nozzle	Slit nozzle	Compound nozzle
Nozzle shape			
Elimination of fins	—	○	○
Spark visibility	○	×	○

Fig. 5 Scarfing results with three different nozzles

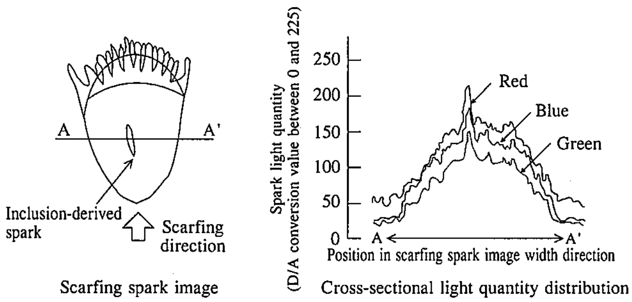


Fig. 6 Check scarfing spark image and light quantity distribution

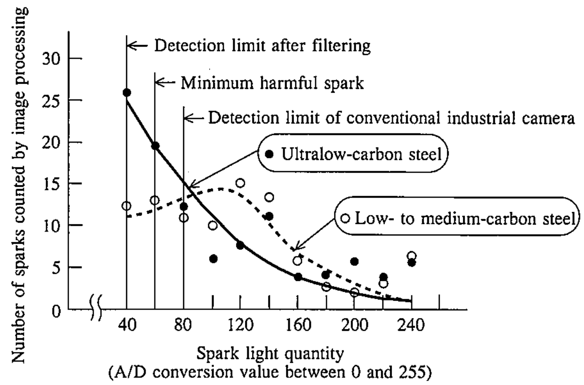


Fig. 8 Spark light quality distribution and camera detection capability

1) They occur on the molten metal bath with a drift component in terms of light quantity,

2) Their emission time is extremely short at 100 to 500 ms,

3) They form and disappear at random in the molten metal bath.

When an attempt is made to detect sparks, the imaging technology to produce images of sparks with good contrast and the high-speed image processing technology to recognize the sparks that instantaneously form and disappear are essential in establishing the spark counting technology of the automatic slab check scarfer.

3.5 Development of spark imaging technology

Sparks derived from minute inclusions formed in low-carbon steel are masked by the molten metal bath light quantity drift, so they cannot be detected by a conventional industrial camera. An analog filter was directly applied to video signals to suppress the molten metal bath light quantity drift and enhances only the spark portions.

A filtered image of a spark and an image of the same spark without filtering are compared in **Fig. 7**. As compared with the spark detection capability of the conventional industrial camera, the filtering camera produces clear images with improved contrast. When scarfing images are processed to count sparks, the detection capability of the filtering camera is high enough to identify minimum harmful sparks frequently generated with ultralow-carbon steel as shown in **Fig. 8**. A band-pass filter with a cutoff frequency of 4×10^{-7} s was adopted as the filter.

3.6 Development of high-speed image processing technology to count sparks

As described in Section 3.2, the two-dimensional shape of the molten pool obtained by optimizing the scarfing conditions is practically constant. The region where inclusion-derived sparks occur in the molten pool is practically stable. Oscillation mark-induced disturbance sparks can be removed by pre-fixing the spark detection region and limiting the image input.

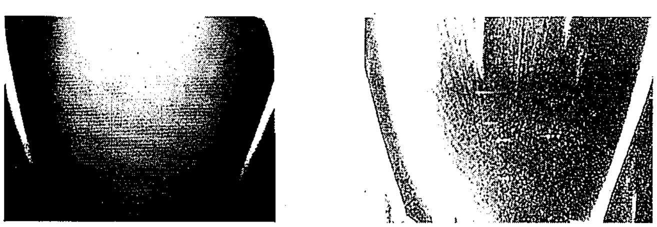


Fig. 7 Difference in spark images with filtering

The light emission of inclusion-derived sparks occurs instantaneously for 100 to 500 ms. To capture the emission phenomenon without fail, it is necessary to record all image frames in 33 ms and detect the sparks. Smoothing filters were employed, preprocessing like compression and expansion was implemented in hardware to increase the image processing speed, and an image comparison method was devised to detect sparks. These measures enabled the continuous detection of sparks within the image capture time of 33 ms.

The image comparison method is explained by referring to **Fig. 9**. A stable molten pool image at the start of scarfing is stored as reference image into a memory. Scarfing images are then continuously entered and all compared with the reference image. Abnormal light quantity portions revealed by this image comparison are taken as candidate spark. The width, length, area, position, and quantity of the sparks are stored in another memory. At the end of scarfing the sparks are distinguished from noise according to these features, and the number of sparks per slab is calculated. Large sparks covering two or more images can be counted with high accuracy by focusing attention on the continuity of spark positions.

If the reference image is not recognizable at a certain length of time after the start of scarfing or scarfing oxygen injection, the scarfing nozzle is judged to have failed to light, and another attempt is made. After the ignition of the scarfing nozzle, continuously input images are monitored for the average light quantity, in order to avoid a quality judgment error due to a flame failure in the scarfing process.

The hardware configuration of the image processing system is shown in **Fig. 10**, and the main specifications of the image processor are given in **Table 1**. Usually during on-line measurement, camera image signals are introduced through the image distributor into the image processor. The camera image signals are also recorded together with the slab number and date on the video tape recorder (VTR). The recorded scarfing images are utilized for such purposes as analysis and maintenance.

Fig. 11 shows the number of sparks counted on-line by the image processing system in comparison with the number of sparks counted by a skilled inspector who scrolled frames of camera images obtained with the automatic check scarfer and visually checked them individually. These two sets of data agree to such a degree that there are no problems with slab quality judgment.

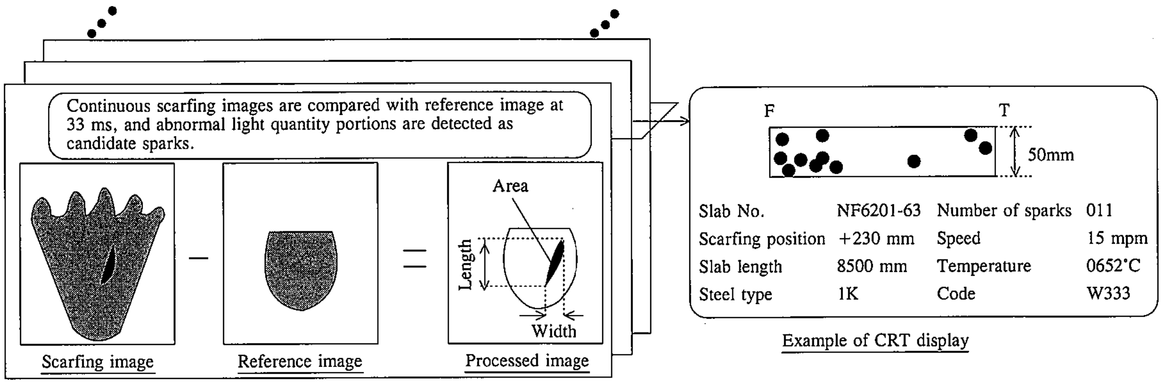


Fig. 9 Spark count image processing

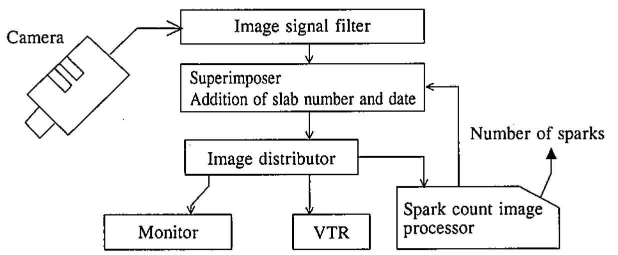


Fig. 10 Hardware configuration of spark count image processing system

Table 1 Main specifications of image processor

Personal computer	NEC FC9801
Preprocessing	Compression and expansion, isolated point removal, and smoothing
Slave processor	MC68020
Main memory	640 kBytes
Image memory	512 × 512 pixels, 8 bits × 16 pictures
Manufacturer	Nippon Steel

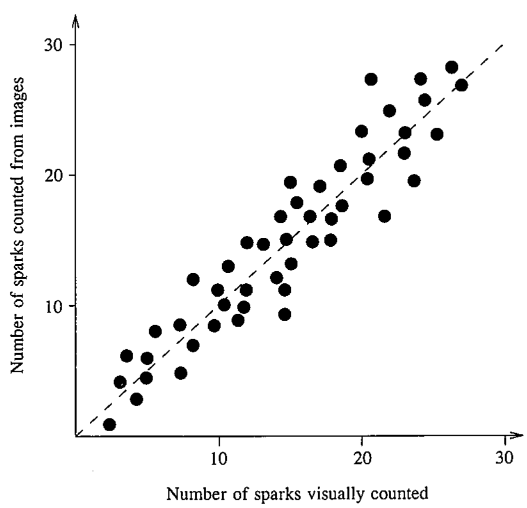


Fig. 11 Results of spark count image processing

3.7 Introduction of diagnostic technology for automatic check scarfer for slabs

The technologies established as discussed above made it possible to detect subsurface inclusions in hot slabs. Since check scarfing itself is a nondestructive inspection, it is extremely difficult to quantitatively control the capability of the automatic check scarfer with standard samples, as done for strip thickness gages, for example. Drilled holes as artificial defects were larger and clearer than sparks to be actually detected, so that they could not guarantee the detection limit of the automatic check scarfer.

Methods were adopted for checking the automatic check scarfer from the two viewpoints of scarfing image brightness monitoring and off-line camera testing. The spark detection capability that has a great impact on the building of quality into products was controlled and maintained by other methods.

1) Scarfing image brightness monitoring (see **Fig. 12**). An image processor, other than the spark count image processor, is separately installed and used to check that the molten pool maintains a normal brightness distribution at the same time when the sparks are counted. Drop in light quantity and other events that directly have an adverse effect on the counting of sparks are detected accordingly.

2) Off-line camera testing (see **Fig. 13**). The camera is tested to see that it has not deteriorated in its sensor performance. The output voltage of the camera in response to brightness measured with an illuminometer is inspected by using a reference light source. This camera testing is conducted every month during scheduled maintenance.

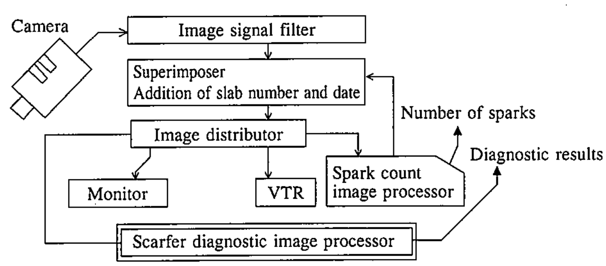


Fig. 12 Configuration of scarfing image brightness monitoring system

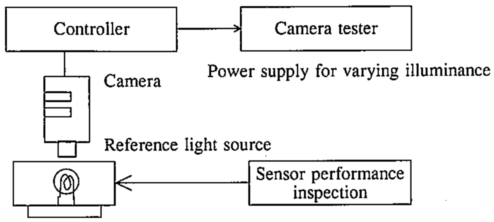


Fig. 13 Configuration of off-line camera tester

4. Benefits of Introducing Automatic Check Scarfer for Hot Rolling Line Slabs

The automatic check scarfer is designed to automatically check scarf hot slabs, automatically count inclusion-derived sparks by image processing, and grade all slabs according to the results of spark counting. This procedure allows the direct hot charge rolling of quality-critical steel slabs whose quality was formerly inspected in the cold condition by hand scarfing. The amount of slab conditioning by hot scarfing was traditionally established flat for all slabs by the grading of casting conditions. The results of actual inspection by the automatic check scarfer makes it possible to set an appropriate conditioning amount for individual slabs.

The automatic check scarfer provides such direct benefits as improvement in the direct hot charge rolling rate, yield gain, and enhancement of quality evaluation accuracy. The quality information of slabs as intermediate products can be fed back to the continuous casting process to permit the short-time evaluation of casting conditions. It also can be fed forward to the inspection processes on the cold rolling and coating lines to increase the exactness and efficiency of surface defect inspection.

The bird's-eye view of the automatic check scarfer is shown in **Fig. 14**, and its main specifications are shown in **Table 2**.

The quality network built around the automatic check scarfer and the system configuration of the network are shown in **Fig. 15**. The automatic check scarfer sets the transverse scarfing position and scarfing speed according to the slab information received from the line control process computer and automatically scarfs the slab. The image processor processes the images of the slab being scarfed and counts the sparks generated from the slab. At the same time, the automatic check scarfer is diagnosed as to scarfing spark image monitoring and other conditions. Once the scarfing conditions are confirmed to be normal, the spark count is sent to the process computer and used to judge the quality of the slab. The process computer specifies the conditioning amount of each slab to the hot

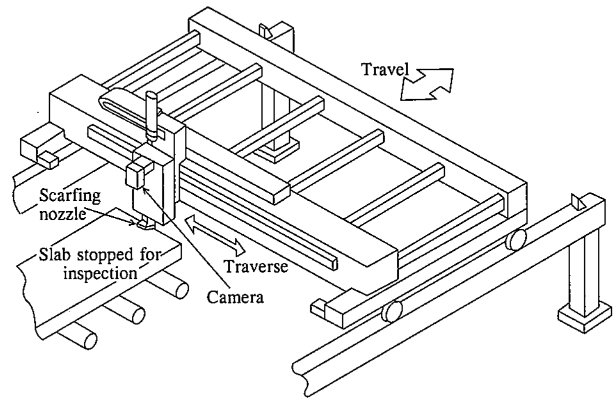


Fig. 14 Bird's-eye view of automatic check scarfer

Table 2 Main specifications of automatic check scarfer

Travel	Stroke : 13 m, Speed : 1 to 20 m/min Drive : DC servomotor, 1.5 kW
Traverse	Stroke : 4 m, Speed : 5 m/min Drive : AC motor + PLG
Lift	Stroke : 650 mm Drive : Air cylinder, 120 mm ϕ
Flying start unit	Escape stroke : 300 mm Drive : Air cylinder
Slabs	Length : 3,800 to 9,230 mm, Thickness : 245 mm Width : 600 to 1,600 mm Temperature : Room temperature to 1,000°C

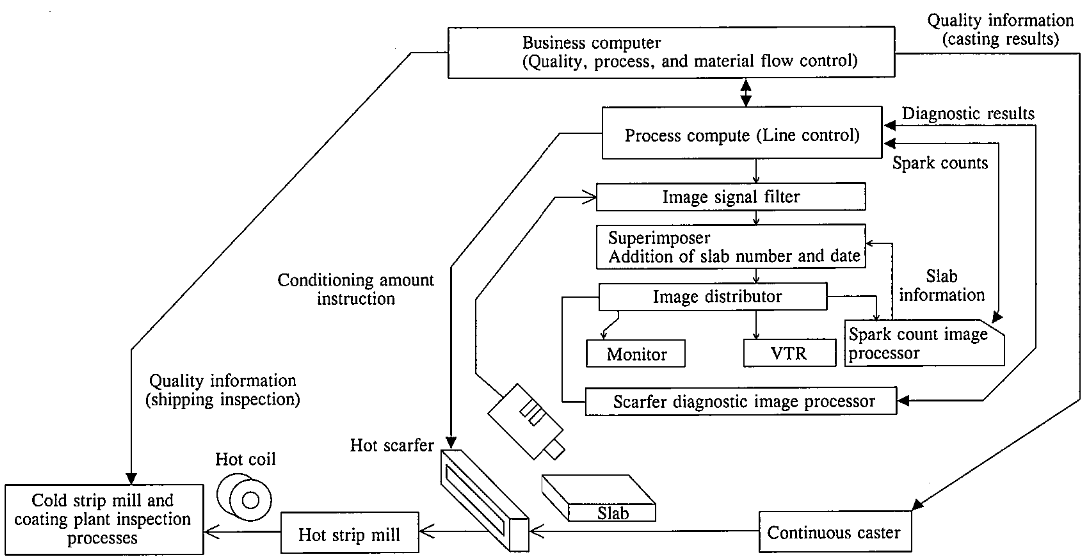


Fig. 15 Automatic check scarfer network at Nagoya Works

scarfer and judges whether or not to downgrade the slab or to apply the slab to another application. The host business computer statistically controls the spark counts and effectively uses the networked slab quality information in the upstream and downstream processes.

The automatic check scarfer system has been working smoothly since April 1992. With its reliability improved by the establishment of diagnostic methods, among other things, the system is now performing at a rate of nearly 100%. The introduction of the system has optimized the conditioning amount of slabs by the hot scarfer: has reduced the percentage of slabs withheld due to inclusions by 0.66% for ultralow-carbon steel slabs, and by 0.21% for medium- and low-carbon steel slabs; and has improved the slab finishing yield by 0.54%. There are many inquiries about the system from Nippon Steel's other works and Nippon Steel's competitors in the steel industry. A study is now under way concerning the building of a sales route for the system.

5. Conclusions

An automatic check scarfer was commercialized for judging the quality of hot slabs. Its development focused attention on the fact that slab subsurface inclusions produce sparks when the slab is scarfed. The automatic check scarfer was developed by making the most of scarfing technology to generate clearly visible inclusion sparks and leave scarfing tracks that exert no adverse effects on the slabs in the next process, and of signal processing technology to count minute sparks in real time. There are many production processes that must be automated and mechanized. The automation and image processing technologies for use in such processes will be further developed.

References

1) Mori, K. et al.: CAMP-ISIJ. 8(5), 259(1995)
2) Kanayama, H. et al.: CAMP-ISIJ. 8(5), 260(1995)