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 Scarring Technology

The establishment of automatic slab check scarring 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 scar slabs in such a way that the scarring 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 scarring machine with vision and intelligence. The problems of the check scarring technology are shown in Fig. 1.

To overcome these problems Nagoya Works started basic research and development in April 1987. Concerning scarring, Nagoya Works tests made various scarfer nozzles jointly with NIPPON SPENG CO., LTD., a hot scarfer manufacturer, and established optimum scarring conditions after persistent scarring 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 scarring 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 Scarring Technology

3.1 Targets of technology development

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

1. Smooth scarring 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%.

3.2 Establishment of spark detection scarring conditions

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

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

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

Another factor that greatly affects scarring 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/cm².

Based on the above-mentioned automatic scarring conditions, the slab temperature was investigated for its effect on spark emissions. Conventional quality inspection by hand scarring 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-
matic scarring of hot slabs was compared with the number of sparks generated by the hand scarring 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 scarring technology

When the slab is scoured, the molten metal is scattered by the kinetic energy of scarring 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 scarring with different nozzles are shown in Fig. 5.

The round nozzle used in hand scarring excels in spark detection as already described, but leaves fins at both sides of the scarring track. There is a slit nozzle that eliminates fins by blowing air to both sides of the scarring track and melting the roots of fins. When the slit nozzle was used, however, the molten pool was short in the scarring direction, and no sparks were generated. A compound nozzle was developed by positioning a round scarring oxygen hole at the center, providing a fin-preventing slit groove on each side of the scarring 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 scarring track.

3.4 Principle of scarring spark emission

The scarring 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. Scarring 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 scarring 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:

<table>
<thead>
<tr>
<th>Item</th>
<th>Round nozzle</th>
<th>Slit nozzle</th>
<th>Compound nozzle</th>
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<tr>
<td>Nozzle shape</td>
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<tr>
<td></td>
<td>Oxygen</td>
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<td></td>
<td>Oxygen</td>
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<td>LPG</td>
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<td></td>
<td>Scarring oxygen</td>
<td>Front view</td>
<td>Scarring oxygen</td>
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<td></td>
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<td>Front view</td>
<td>Front view</td>
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<tr>
<td>Elimination of fins</td>
<td>—</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Spark visibility</td>
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Fig. 5 Scarring results with three different nozzles
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 scarifying 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 $4 \times 10^{-3}$ 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 scarifying 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.

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 scarifying is stored as reference image into a memory. Scarifying 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 scarifying 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 scarifying or scarifying oxygen injection, the scarifying nozzle is judged to have failed to light, and another attempt is made. After the ignition of the scarifying 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 scarifying 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 scarifying 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.
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 scarifying 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 scarifying 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) Scarifying 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.
4. Benefits of Introducing Automatic Check Scarf for Hot Rolling Line Slabs

The automatic check scarfer is designed to automatically check scar' 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 coiler.
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