Detection of Mold Level Fluctuation in the Continuous Casting Process with Thermal Image and Surface Disturbing Evaluation

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There is a close correlation between the fluctuation of the steel mold level and the occurrence of surface defects of final products. In recent years, the Eddy current sensor has been widely used to detect the fluctuation of the mold steel level. But the detection range of the eddy current sensor is restricted to the local area. Some fluctuations of the local area would be ignored. In order to provide a better reference for detecting the signal for the mold level, a new detecting technology based on thermal imaging and surface disturbing evaluation was established to record and analyze the images of the steel mold surface in the continuous casting process. The results found by the thermal imaging camera showed different characteristics in the fluctuation of the steel mold surface (such as SEN clogging and abnormal Ar bubble injection). The surface disturbing evaluation is calculated by the method of utilizing continuous thermal image differential computation. The results showed a clear and strong relationship between the surface disturbing evaluation and the quality of hot rolled steel. The field experiments data in this study have demonstrated that this new technology can be practically implemented and provide adequate results.

Keywords: The mold level, Thermal image, Surface disturbing evaluation

1. INTRODUCTION

Slag entrainment during the continuous casting of steel is the major cause of sliver defects on hot rolled steel products. There is a close correlation between the fluctuation of the steel mold level and the occurrence of sliver defects of final products. Technical literature indicates that there are some factors that can affect the fluctuation of the steel mold level such as the size of mold, casting speed, the shape of SEN, depth of SEN and AR flow rate during casting(1-3). In recent years, the Eddy current sensor has been widely used in CSC to detect the fluctuation of the mold steel level and control the steel flow during casting. However, the detection range of the Eddy current sensor is restricted to the local area. Some fluctuations of local area such as the edge of the mold would be ignored. The ratio of sliver defects at the edge of hot rolled steel coil is more than any other position, so the narrow side Eddy current sensor made by VUHZ was installed in CSC(4), and the QE number was set by the detected information from the sensor. The QE number is used to compare with the hot rolled steel coil defect rate, but there is not much correlation between the QE number and the defect of steel coil. In order to understand the phenomenon of slag entrapment, a thermal camera was used to record the image of the steel mold surface during the continuous casting process in CSC.(5)

2. RESEARCH METHOD

The main reason for choosing a thermal imaging technique is that the brightness contrast of the steel mill environment is too high. It is difficult for a normal image sensor camera to capture a clear image of the fluctuation of the steel mold level. The difference of visible image and thermal image is shown in Figure 1. The thermal image can capture more clearly detailed information from the mold surface than a normal image sensor. Limited by the environment of the steel mill, the position of the thermal camera was installed above the copper mold. The camera with 7 degree telescope lens was used in this study to record the fluctuation of the steel mold level. The result of the thermal image is shown in Figure 2, and the oscillation of mold surface was very clear. In order to improve the efficiency of judgment for the oscillation of the mold surface and avoid judgment by human error. A system was developed to calculate the surface disturbing evaluation to quantify the fluctuation of the steel mold level(6). The surface disturbing evaluation is calculated by a method utilizing continuous thermal image differential computation.

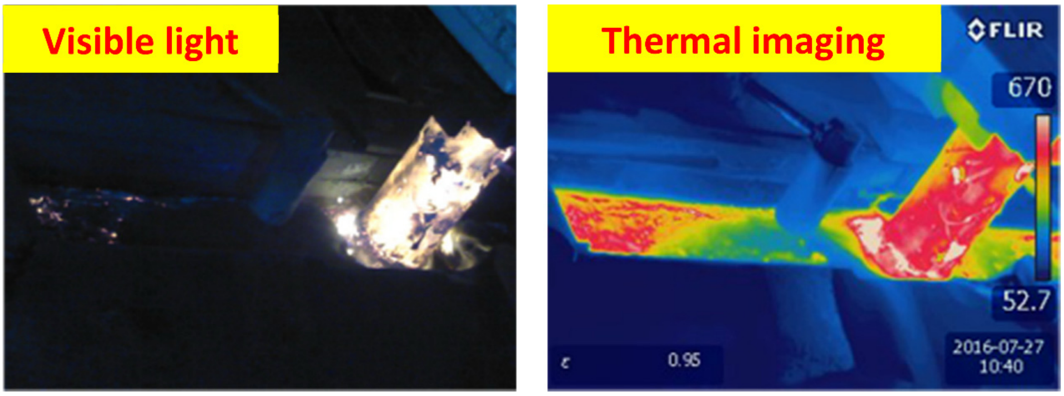

Fig.1. The difference of visible image and thermal image.

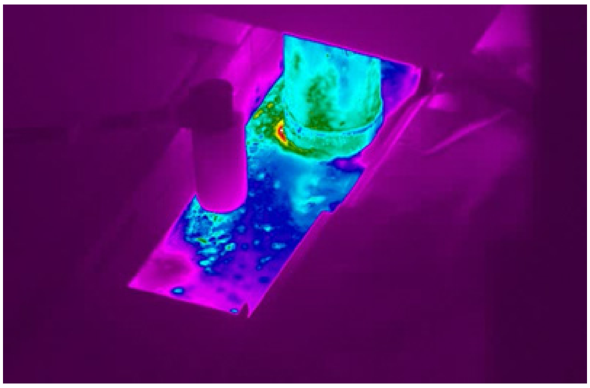

Fig.2. The thermal image of the mold level.

3. RESULTS AND DISCUSSION

A much clearer image of the mold surface can be gotten by using the thermal camera, and the fluctuation of the mold level is easily observed. The first thing needed to be solved was to automatically analyze the thermal image, if this technique is to be used in the steel mill. The result of the calculation of the surface disturbing evaluation which was developed in this research is shown in Figure 3. The analytical frequency was 25 and the analytical area was at the narrow side of the mold. The fluctuation of the steel mold level was calm for the most part during the casting process. There were some abnormal waves at times which are marked by the red circle, but the eddy current sensor did not show an unusual signal at that same time. Inspection of the slabs found sliver defects at the location of the abnormal signal.

In general, the fluctuation of the mold level was small during the casting process, but some abnormal fluctuation could be found by thermal camera. Three different characteristics in the fluctuation of the steel mold surface from the thermal camera are defined in this study. The first abnormal type is caused by SEN clogging. The evolution of the clogging index during the cast is shown in Figure 4. Using thermal imaging to check this cast, the fluctuation of the mold level was likened to waves on the ocean when serious SEN clogging occurred (the clogging index was raised from 0.2 to 0.6). The cross section of the SEN used in this casting is shown in Figure 5, and some clogging was found at the bottom of the outlet. The CFD method was used to simulate the influence of SEN clogging with the same position, and the results are shown in Figure 6. The turbulent energy of the mold surface with SEN clogging was one time larger than that of SEN without clogging. The higher turbulent energy represented in the fluctuation of the mold level was bigger and the simulation result was similar to the result of the thermal image. It could have been handled early when the fluctuation of the mold level was like waves on the ocean.

The second abnormal type was a breathing phenomenon. From the thermal image result, the characteristic was clearly observed in the fluctuation of the mold level moving up and down evenly in a short time and the fluctuation range was huge. The breathing phenomenon often occurs at the second or third slabs of the first furnace, and it is caused by slab bulging. The casting speed would be slowed down to reduce the fluctuation but the mold level still continued the oscillation after reducing

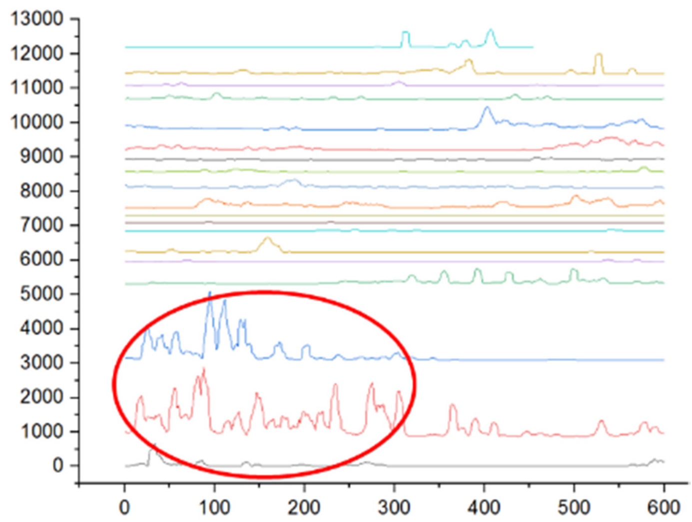

Fig.3. The calculation results of the surface disturbing evaluation.

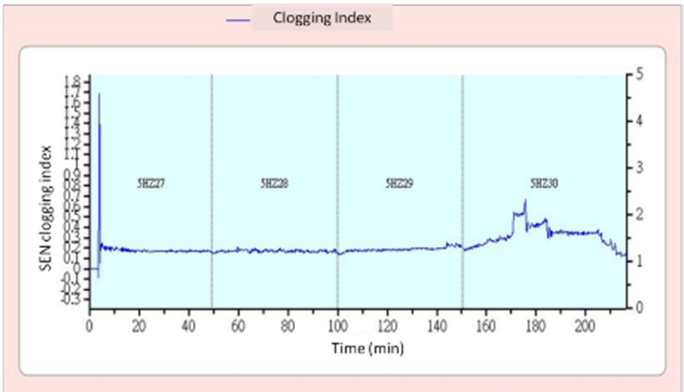

Fig.4. The evolution of clogging index during casting.

Fig.5. The cross section of SEN with clogging.

the casting speed. The sliding gate position after reducing the casting speed is shown in Figure 7, and the CFD method was used to simulate the sliding gate open and close frequency at constant casting speed. It was observed that the same breathing phenomenon occurred in the simulation result.

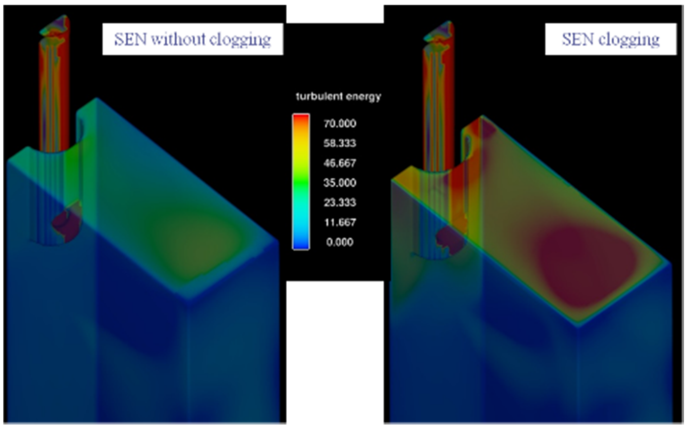

Fig.6. The simulation result with different SEN conditions.

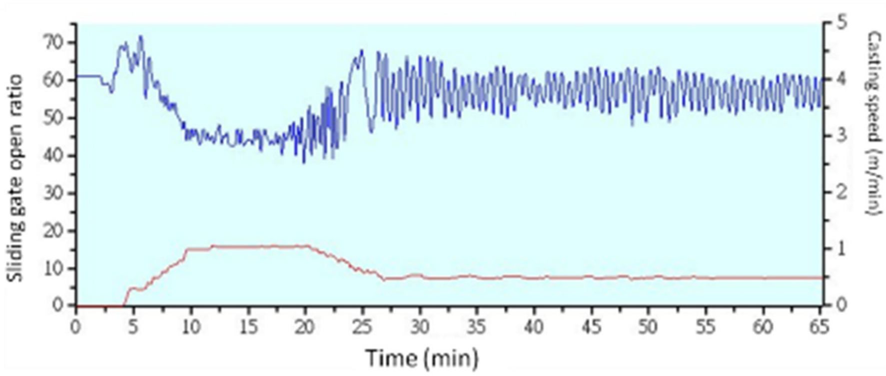

Fig.7. The evolution of the sliding gate open ratio after reducing the casting speed.

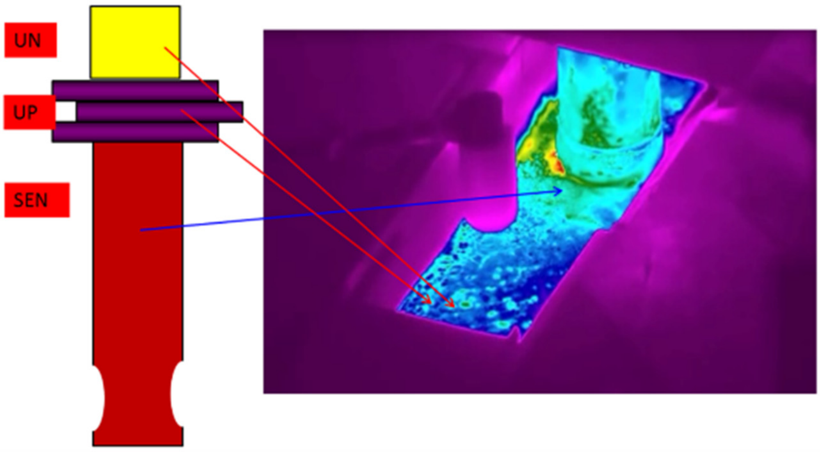

Fig.8. The influence area with different Ar injection position.

The third type was the abnormal fluctuation at the narrow side of the mold. This type was very difficult to be detected by the normal Eddy current sensor, and the sliver defect at the coil edge was related to the abnormal fluctuation at this position. There are a lot of reasons to cause the fluctuation at the edge of mold. The Ar flow rate at different positions (such as upper nozzle, upper plate and SEN) was adjusted and a thermal camera was used to observe the change in mold level. The fluctuation area where the Ar flow rate was adjusted bigger is shown in Figure 8, From the Ar flow rate test result, the fluctuation at the edge of the mold would be serious when the Ar flow rate of the upper nozzle and upper plate increased. It was an important parameter to control in the fluctuation of the mold edge by adjusting the Ar flow rate of the upper nozzle and of upper plate .

4. CONCLUSION

The fluctuation of the steel mold level causes slag entrapment of the slab and is hard to be detected by the eddy current sensor because of the restriction of the detected range. In this study, a thermal imaging technique is used to record the surface of the mold level, and the image can capture more clearly detailed information than a normal image sensor camera.The surface disturbing evaluation is calculated to define the scale of the mold level, and it shows a clear and strong relationship between the surface disturbing evaluation and the quality of hot rolled steel from the results.

The results of the thermal image show different abnormal characteristics in the different types of fluctuation. Comparing the thermal image and the parameters of the casting process, the fluctuation could be classified as SEN clogging, abnormal Ar bubble injection and breathing phenomenon caused by the bulging of slabs. The thermal imaging technique can help engineers to backtrack the origin of slab defect, and avoid the slab with defects beingsend to further process.

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