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A NEW VIBRATION LADLE SLAG DETECTION SYSTEM

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ABSTRACT

Recent years, vibration ladle slag detection was the most widely used continues casting ladle slag detection technology as the lower cost and the convenient operation. The hardware and software of system improvements were been made to increase the alarm accuracy. On the hardware side, several generations of ladle operating arm vibration signal detection device were developed, the vibration acceleration signal to noise ratio steadily increased. On the software side, the special detection algorithm was established based on the fourier transform and wavelet transform. The new system had already applied in several steel continues casters. The system achieved no less than 95% alarm accuracy with the new algorithm, and can distinct the full-steel, mix-slag and full-slag vibration signals. The sensitivity was about distinct the slag signal and alarm in less than 1s.

Keywords: Ladle operating arm, Vibration detection device, Fourier transform and wavelet transform, Vibration energy.

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INTRODUCTION

With the economic crisis continues, the steel industry is experiencing cold, steel mills around the world are more urgent pursuit of new cheap technologies which can improved product quality to enhance competitiveness. The ladle slag detection technology in casting process was of these type efficient technologies, the benefits include: improved steel cleanliness and quality, reduced slag type breakouts, improved casting consistency, increased tundish life time, increased yield, little maintenance and low-cost [1].

Because of its high efficiency, the ladle slag detection technology is viewed as a key technology for continuous casting, and has attracted great attention in the world. Since 1980s, the electromagnetic ladle slag detection system was first developed by Julius E, etc in the Aachen University of Technology Institute of Metallurgy [1,2]. The world's metallurgical researchers have developed various ladle detection methods based on different principles, such as ultrasonic detection method [4], infrared detection method [5,6], vibration detection method [7], weight detection method [8,9] and so on. For the widely used of protective casting, the infrared detection was no longer suit for ladle slag detection. The ultrasonic method and weight method were due to the various reason, did not get promoted.

Electromagnetic detection method is based on the difference permeability of molten steel and slag to detect the outflow of ladle slag through the shroud. Because of its mature technology, high sensitivity and developed firstly, electromagnetic detection method is the most widely used method. However, the system needs to reform the ladle bottom to install the sensors, and the sensors require periodic replacement for high temperature at the bottom of ladle, so maintenance costs are relatively high.

Vibration detecting method is based on the difference vibration of shroud induced by the molten steel and slag. When the molten steel in ladle outflows through the shroud to tundish, the flow impact will induce the vibration of shroud as well as operating arm which connects with shroud. The larger the shroud open degree and steel flux is, the stronger the vibration is. For the slag is one third specific gravity of liquid steel, the vibration states induced by slag and liquid steel must be different. Therefore, the flowing state of the liquid steel and slag can be detected indirectly by detecting the vibration of operating arm. Vibration detecting method firstly origins from the site practice of molten steel casting. The experienced operator can judge the slag quantity with hands feeling the vibration change of operating arm at the last period of casting process before judging by eyes. Vibration detection systems are easy to install and operate, as the sensor installed in the shroud manipulator arm far away from molten steel. Meanwhile, the sensor lifetime can be up to several years. With technology matures and steel mills increased pressure on cost control, vibrating detection systems widely used recent years. Compared with the electromagnetic detection system, the biggest disadvantage of vibration detection system is that the quasi-quoted rate is not high, because the manipulator arm vibration has a large number of interfering signal and strong noise; the effective vibration signal is week, and the unstable flow characteristics of liquid steel and slag. The key to development of vibration detection technology is to eliminate the interference, increase the effective signal to improve the detection sensitivity.

In order to improve the detection accuracy, the hardware of the detection system was change several times, to remove interference and enhance the effective signal. The algorithm was optimized combining the fast Fourier transform and wavelet analysis. The system can effectively distinguish liquid steel flow, slag entrapment and slag down signal. The system is also a rapid response system for its simple and it conducive to continuous casting operation.

VIBRATION LADLE SLAG DETECTION SYSTEM COMPONENTS

While the molten liquid steel flows from the ladle into the tundish through the shroud, the slag detection system monitors the vibration of the manipulator arm. Once the slag signal was detected, the system sends corresponding audible alarm signals, close the slide gate, the response time is less than 100ms. A typical ladle slag detection system mainly comprises a vibration signal detection device, a signal processing device and output device, the components diagram is shown in Figure 1.

As shown in Figure 1, the related cells were the vibration signal collection device and signal process device to improve the detection sensitivity and accuracy. For the signal collection side, the purposes of device reform were to isolate the interference signal and amplify the valid signal. For the signal process side, the hardware technology had been basically mature and stable, the improve pace is limited, so the improvement mainly focused on the algorithm optimization.

IMPROVEMENT OF DETECTION HARDWARE

According to system working principle, the precondition of vibration slag detection system is that it can detect correctly the vibration signal of shroud. In the traditional detective mode, sensor is fixed directly on the operating arm connecting with shroud. The vibration signal which caused by the flowing molten steel and slag is detected by sensor after transmitted. The detective mode is shown in Figure 2.

Because of the complex vibration situation in continuous casting, many external interferential factors will influence the vibration of operating arm, such as, ladle sitting, lifting operator arm, open/close the slide gate, traveling crane moving and etc., therefore the veracity and reliability of detected signal is influenced. The traditional detective mode does not consider how to avoid the disturbance and noise with sensor fixed directly on the operating arm. Its largest advantage is the easy and simple installing and operating mode.

For the detection system, the vibration source is the shroud, however for the high temperature and casting operation, it is impossible to install the sensor directly on the shroud. In order to achieve the approximate effect of the sensor mounted to the shroud, a signal collection device with an arm hold the shroud was design as shown in Figure 3. As shown, there was an induction sheet close to the shroud with a rod which was driven by a motor as one can retractable arm. The sensor mounted in the rod tail. The rod connection with the manipulator arm has a dedicated vibration isolator to prevent the incoming of interference. The aim of this designed was very clear to collect the strongest valid signal. And the sensitivity also increased unprecedentedly. However, this design also has drawbacks. The joining of induction sheet and supporting device made the operation of manipulator arm become complicated, and the action of induction sheet required very precise. Some small manipulator arm cannot stably support the system for the extra weight. For these reasons, some mills site operator did not welcome the system.

In order to inherited the advantage of the system shown in Figure 3 and overcome its shortcoming, a new system had designed, which installed as the traditional way, but would been more sensitive, as shown in Figure 4. In this system, all the keys were concentrated to a small box, such as the sensors, the resonance means and cooling means. This design utilized resonance principle, the inherent frequency could be adjusted close to the special slag frequency to resonance, so as to amplified the valid vibration signal, also could filter out other frequency interference and noise, so called self-sensitization detection system. This system inherited the advantage of both the aforementioned styles, brought the increased sensitivity and simple operation.

ALGORITHM OPTIMIZATION

Vibration detection is intended to distinguish slag down signal as fast as possible, strive to alarm and close the slide gate before the slag flow to tundish. The collection signal was X, Y, Z three directions of vibration signals, but only as a practical analysis of three one-dimensional signal. There are many methods to process the signal, for example, time domain analysis, frequency domain analysis, statistic analysis, correlation analysis, wavelet transform, etc [10].

The principle of slag detection is the density different of liquid steel and slag. When the ladle liquid flow down through the shroud, the impact energy inducted by mixed slag or all slag is less than that induced by all steel. After the optimized of signal collection device, the origin vibration intensity could display the difference of steel flow and slag flow. The typical vibration signal was shown as Figure 5(a). As shown, the vibration amplitude suddenly reduced about 3 second before the slide gate closed (X, Y-axis became smaller, Z axis was particularly significant). The change of amplitude represented the weakening of vibration energy that a large part of slag flew through the shroud. For this typical vibration, slag signal characteristics significantly, the algorithm does not require particularly complex to be identified. However, the ratio was about 70% even after the hardware improvement. And for the others, there was no significant change in the vibration energy when slag down, just as Figure 5 (b) shown. Additionally, there were many factors could induce the flow energy unstable, such as the repeatedly operation of the slide gate. So if only there is a simple energy method identification, alarm rate is difficult to achieve steel mills needs, while also prone to a large number of false alarm.

During optimizing the collection device, it found that there was sensitive frequency for slag carry over ladle. Even for the typical vibration that energy obviously reduced when slag down, there were certain frequencies changed more obviously than the others. Through the water model experiment and site signal analysis, it was found that the complete typical ladle slag carry over process included the following stages: the ladle liquid surface reduced as the molten steel flowed down to the tundish through the shroud; vortex formed from the unstable steel surface, entrapped the slag above the liquid steel; the vortex extended into the shroud even through; a lot of slag flow down.

Since the vortex itself was generated from the surface instability, it was difficult to keep stable, and therefore the characteristics of the slag flow were also changeable. However, due to the gravity and the size of ladle and shroud were fixed, so there were corresponding sensitive frequency bands.

For the typical slag flow down, a large part ofslag mixed with steel flown down when the steel surface reduced close to the bottom, the vortex was not obvious and speed was not fast. The impact energy to shroud significantly reduced due to lower slag density.

For the unstably slag flow, usually appeared more obvious vortex, the slag was entrapped into the Involved in the whirlpool center. The whirlpool front usually hit against the shroud wall and could not through to the tundish. Due to the higher speedsof vortex center and little part of slag, the vibration energy would not drop instantly but rise simultaneously. It was often only one or two direction energy increased for the random hit. With the amount of slag increase the energy would slowly reducedagain. However the variety of vibration would be complex than the typical style, and be difficult to detect, the signal in Figure 5 (b) was the case. In order to identify these more complex situations, and to reduce false alarm, a more accurate algorithms was urgently needed.

In the early algorithm study, many vibration processing methods were tested and compared: Fast Fourier transform, short-time Fourier transform, wavelet analysis, chaos and nerve cell method, and Hilbert Huang Transform (HHT), etc. according these methods,analysis the vibration amplitude, frequency, mean, variance, correlation function, etc., look for the slag characteristics. It was found that the different method had different advantage, especially for chaos and nerve cell method and Hilbert Huang Transform (HHT), although the algorithm was very subtle, but it did not suit to apply on-site. For the chaos and nerve cell method, the practice time of each caster was too long; for the HHT method, the respond speed was too slow for detection requirements. Eventually, a simple and efficient method was adapted that tracking sensitive frequency energy using wavelet analysis.

Figure 6 is the corresponding analysis results of Figure 5. For the typical vibration case as shown in Figure 6(a), the characteristic of energy reduced was still evident. For the unstable vibration case as shown in Figure 6(b), the carves exhibited different characteristics in the X-axis and Y-axis, the increased energy indicated the slag entrapped by vortex when the slag would increase immediately. As can be seen from the figure, the slag down period in (b) last a few second more than in (b), which was due to the vortex front reached the shroud in the case (b), but the slag had not officially flow down and the surface of steel were higher than the case in (a). So it was forecast the slag down in case (b).

As mentioned above, through the optimization of hardware and software, the detection system could distinguish the different flow cases as: liquid steel flow down the ladle, slag entrapped by instable vortex, and a large amount of slag carry out with the steel through shroud. No matter which the situation, it could be identified by the optimized algorithms within 0.5s. Actually, in order to prevent false alarms, the identification time was usually extended to about 1s.

The new system was put into work in several castersfrom 2012. Detection statistical results of two casters in different mill were listed in Table 1. The data shown that the Accuracy alarm rates were stably above 95%, achieved the steel mill requirements.

CONCLUSION

With long time prophase research and repeated tests, considering field environment of steelworks, the dissertation optimized the mechanical design of the detective mode and researches successfully the new-style high sensitive device. It has incomparable advantages on signal detection. And in the algorithm, a simple way was adapted that tracked the sensitive frequency using wavelet filtering. The key of this system was to determine the sensitive frequency and induce resonance. For the same caster, sensitive frequency unchanged. So the hardware device must be sensitive to this frequency. It was generally recommended that the detection system configuredspecially manipulator arm to make sure that the self-sensitizing vibration detection device could play the greatest role.

In the new system on-site, the valid signal was enhanced, the characteristics of slag down were obvious, and detected rapidly. System ensured rapid identification slag signal within 1s. Its application fully meted the demand of steel mills.

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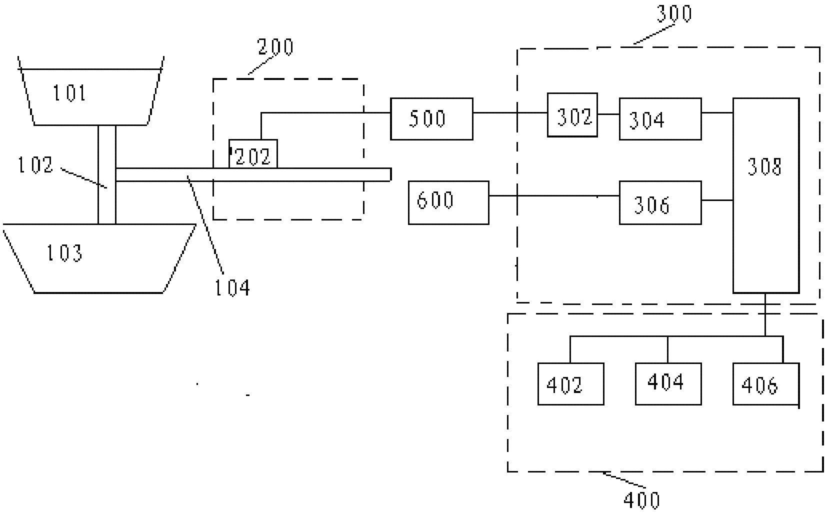
Table 1. Detection statistical results

Caster	Identification rate		
	Testing heats	Correct alarm heat	Alarm rate
A	300	287	95.7%
B	210	202	96.2%



101-ladle 102-shroud 103-tundish 104-manipulator
202-vibration collection device
302-signal conditioner 304-signal collection card
306-signal input and output control card 308-IPC
402-alarm unit 404-slide gate control unit 406-display unit
500- Junction Box
600- Operation box

Figure 1. Schematic diagram of vibration detection system components.

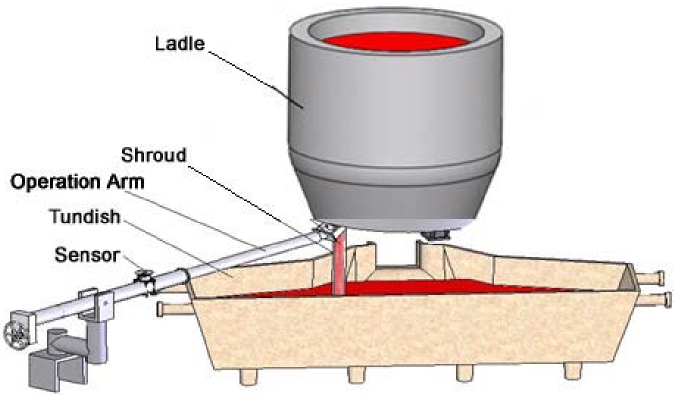


Figure 2. The traditional detective mode.

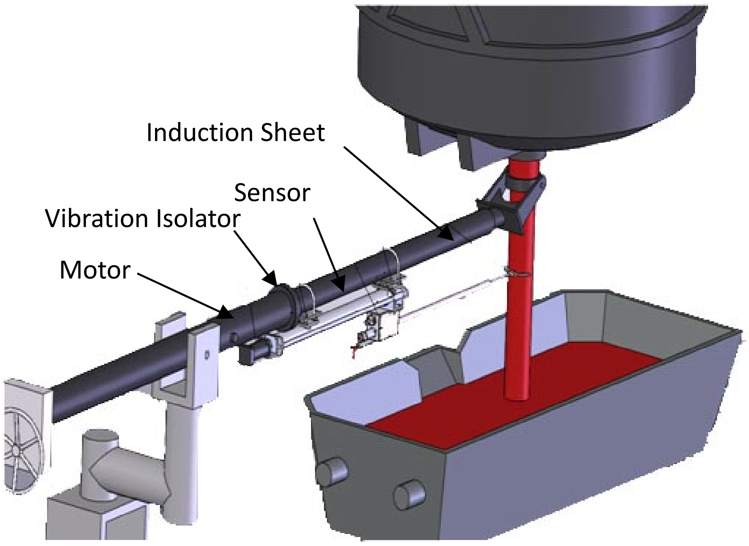


Figure 3. The detection system with “arm”.

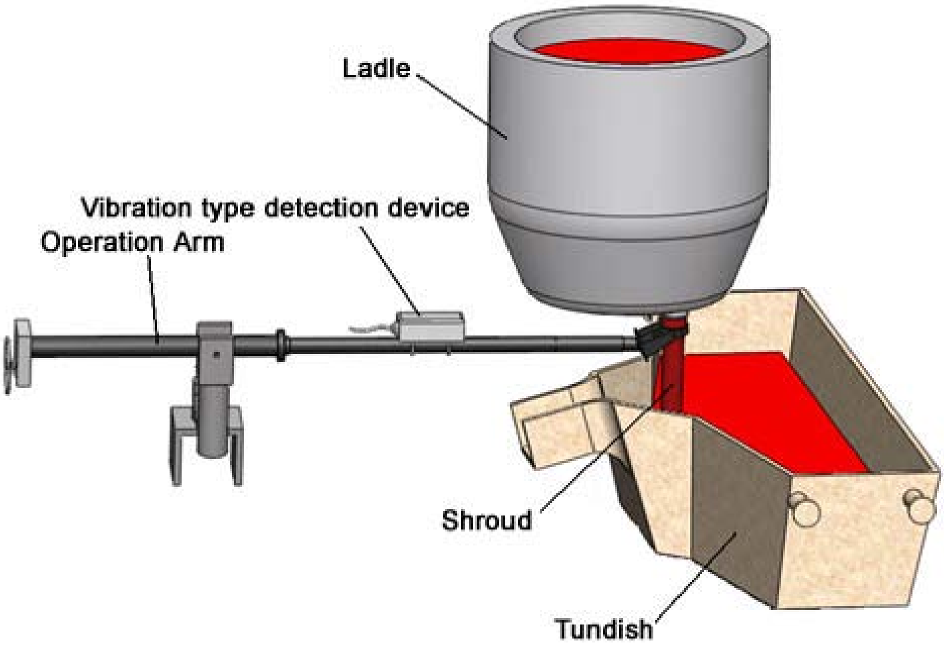


Figure 4. New detective devices--self-sensitization detection system.

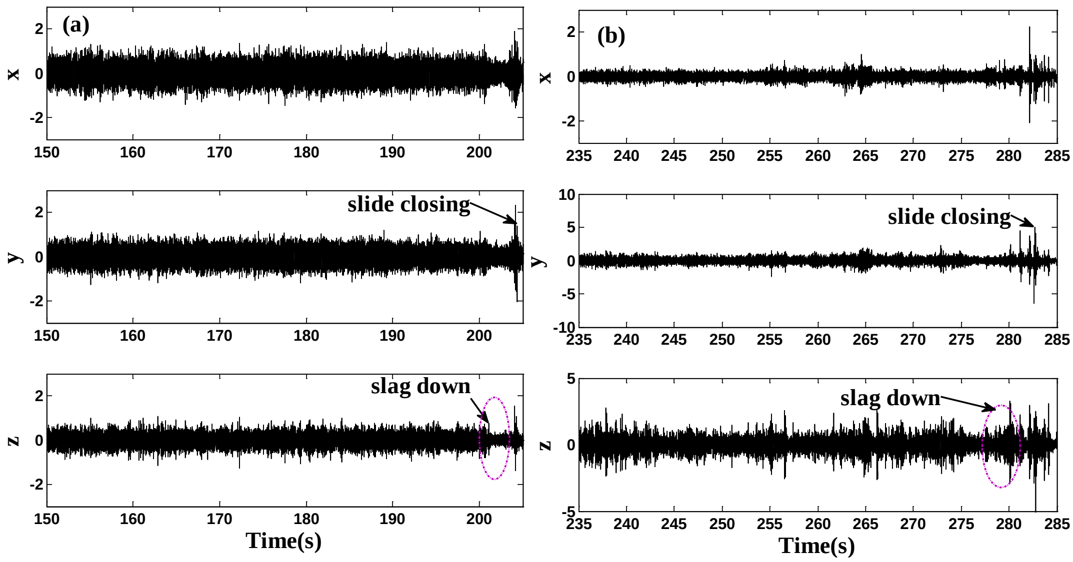


Figure 5. 50 second origin vibration signal of two furnaces in different steel plants before the slide gate closed:
(a) Typical vibration (slag down period was 200 - 203s, slide gate closed at 203.1s)
(b) Typical vibration (slag down period was 277 - 283s, slide gate closed at 283.5s)
Note: The Abscissa: the detection time, the Ordinate: X, Y, Z-axis acceleration value.

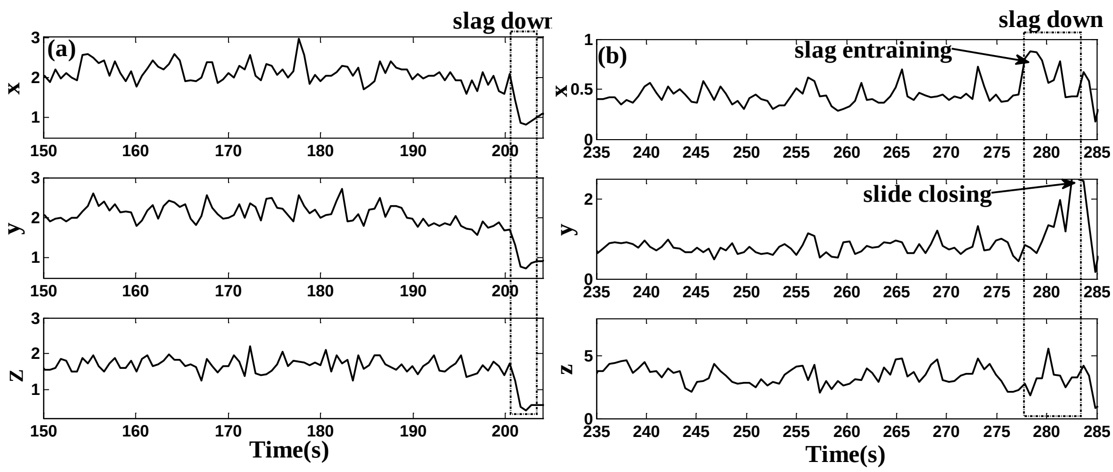


Figure 6. Vibration characteristics filtered by wavelet decomposition with origin data in Figure 5.