SLAG DETECTION IN THE CONTINUOUS CASTING MACHINE YESTERDAY, TODAY AND TOMORROW[1]

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Abstract

Carry-over of oxidised ladle slag into the tundish was a major problem in steel-making 20 years ago. With the application of electromagnetic slag detectors, the average slag carry-over into the tundish was significantly reduced, allowing the production of high quality steel combined with a significantly increased yield. With the beginning of automatic slag carry-over monitoring and the automatic closing of the ladle gate, there was also an increase in the requirements of a slag detection system, in terms of reliability and secure operating. With the clear, flexible, evaluation and display of system performance, the users at operation, maintenance etc., can gain a rapid and precise overview of the system's condition and benefits. With the use of slag particle detection, i.e. with the expansion of the spectrum of sensitivity, extremely high requirements of steel quality will be met in the future. The very best operating point and yield/slag carry-over can usually be set for any steel quality.

Key words: Slag detection; Slag carry over; Yield improvement; Detection of slag particles.

DETECÇÃO DE ESCÓRIA NO LINGOTAMENTO CONTÍNUO. ONTEM, HOJE E AMANHÃ

Resumo

A passagem de escória da panela para o distribuidor foi um problema nas Aciarias há 20 anos atrás. Com a aplicação de detectores eletromagnéticos de escória, a quantidade média da passagem de escória da panela para o distribuidor foi significativamente reduzida, permitindo a produção de aços com qualidade superior ainda combinado a ganhos de rendimento líquido importantes. Com o advento da monitoração automática da passagem de escória e do fechamento automático da válvula gaveta, houve também um aumento das exigências para se ter um sistema de detecção de escória de alta confiabilidade e com segurança operacional. Com a visualização e monitoração simples, clara e precisa da performance do sistema, os usuários da operação, da manutenção e da qualidade podem obter rapidamente as informações desejadas. Com o advento do novo sistema Detector de Partículas de Escória, através da expansão do espectro da sensibilidade, as novas exigências para aços com qualidade extremamente elevada serão alcançadas no futuro. O ponto ótimo de operação e rendimento/passagem de escória pode ser determinado para todos os tipos de aço.

Palavras-chave: Detecção de escória; Passagem de escória; Rendimento líquido; Detecção de partículas de escória.

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Introduction

The start up of the first continuous casting machine 1961 at Dillinger Hütte and further developments in this field up to the thin slab casters today were always accompanied by an increasing demand for high quality steel grades. The carry over of oxidized slag from ladle to tundish during casting is one important source of undesired inclusions in the final products. Therefore slag free casting became more and more important taking in consideration optimized yield. Consequentially an automatic slag detection system at the continuous caster is today an essential tool for the controlling of the casting process and the optimization of steel quality and yield.

Slag detection measuring principles

25 years ago there was mainly one method existing for slag detection namely observing the casting stream between ladle and tundish or the surface of the tundish for a changing in emission whereby the difference in emission between slag and steel is really hard to see. Therefore this method depends strongly on the reliableness of the operator.

Alternatively another method was used: feeling the change in vibration at the ladle shroud manipulator arm during the end of casting. Among other things the change in vibration is also caused by the difference in density of steel and slag which is in the range of factor 2 - 3.

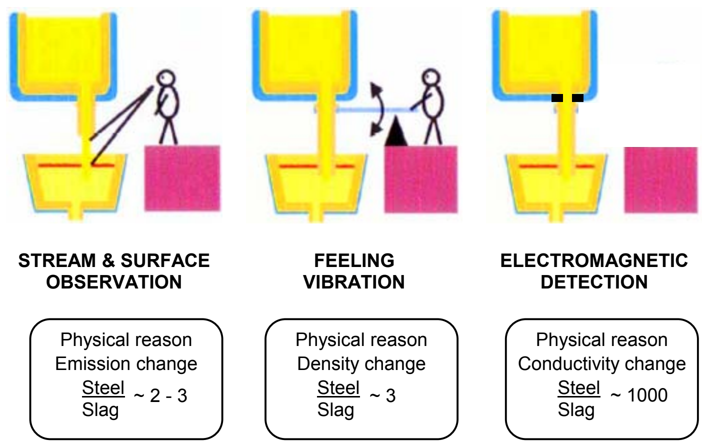

Fig. 0: Slag detection measuring principles

Already in the eighties, the first electronic vibration systems have been developed.[1] But from the beginning it became obvious that in a steel plant many sources are also creating disturbing vibrations, vibrations in the same spectrum as created by the slag carry over. So – for example - gate movement, Argon flow rate changes, ladle shroud cracks, crane movements, movement of ladle turret, acoustical horns etc. may result in a false alarm with an early slide gate closure.[2] To reach an acceptable reliability, filtering technologies were developed. But even after a long commissioning and teach in time, only some of these disturbances can be filtered out - others not. In addition, each change at the caster may request recommissioning. Consequently a high reliability and trouble free operation may not be reached all the time.

Taking in consideration that this vibration-disturbances always exist in steel plants and high reliability is needed for automatic gate closure, a new idea was generated - electromagnetic slag detection which is physically based on measuring the big difference in electrical conductivity. Steel has a 1000 times higher conductivity than steel. This leads to a much higher measuring sensitivity followed by high signal to noise ratio resulting last not least in a slag detection performance and reliability of more than 99 %.

Very high benefits, highest reliability, secured steel quality and optimal yield made the electromagnetic slag detection system to the world wide standard.

Electromagnetic slag detection sensors

The direct measurement method with electromagnetic fields uses the difference in electrical conductivity of slag and steel (factor 1000). Eddy currents are induced in the casting stream and the difference in the amplitude and phase in the resulting magnetic field is detected while slag appears at the end of the heat.
Basically two sensor arrangements were adopted at the beginning for slag detection. One is mounting two discrete sensor cassettes, a transmitter and a receiver sensor in opposite position to the casting stream above the slide gate. The second one is a sensor arrangement surrounding the casting stream mounted in a single cassette above the slide gate.

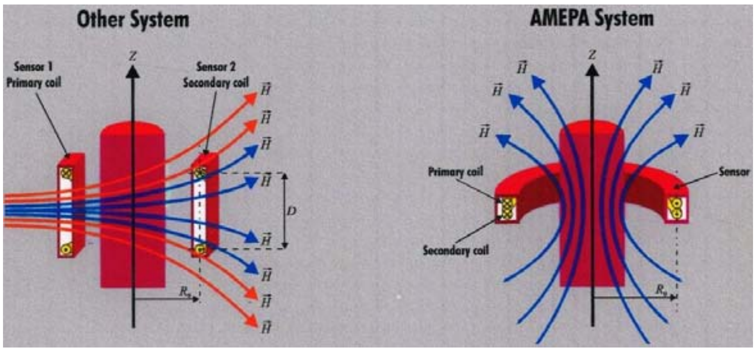

Fig. 0: Electromagnetic field for double and single sensor configuration

Fig. 0 shows the different distribution of the electromagnetic field in the measuring area which clearly demonstrates the higher measuring sensitivity of the single sensor configuration.
A second advantage is that a single sensor cassette is much easier to install than two sensor cassettes. Therefore the single sensor arrangement, today installed at more than 300 continuous casters with over than 2500 ladles has become the state of art for electromagnetic slag detection.

Single sensor installation

A quarter century ago the first single sensor was integrated in the ladle well block. At that time the lifetime of the sensor was the same of the ladle well block and has to be changed frequently.
A few years later the first single sensor was installed in a casette below the well block. The lifetime increased from several weeks to an average of more than 6 month.
The lifetime of the sensor, mounted above the slide gate plates is influenced mainly by two circumstances: steel penetration because of damaged ladle lining and mechanical damage during relining.
The newest version of sensors is protected by a solid steel ring against mechanical damage without influencing the overall measuring sensitivity. Today an average lifetime of more than 18 month is achieved up to a peak value of 8 years.

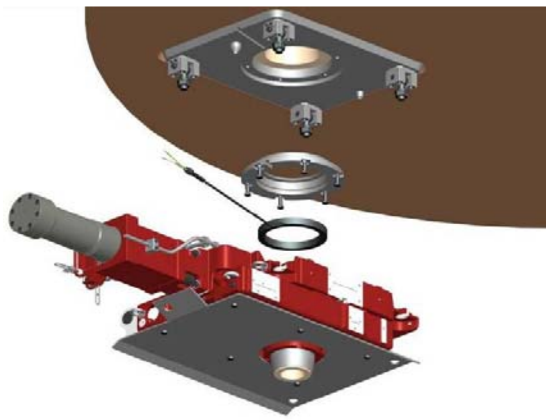

Fig. 0: Changeable sensor in a modern ladle slide gate

To optimize the handling of sensor changing intensive discussions with some main slide gate suppliers have now influenced the design of their newest slide gate generation. Fig. 0 shows an example of the one of the most modern slide gate generation.[3] When the gate is opened for changing the plates and if the inner nozzle is removed the sensor can be replaced very easily.

System description for the AMEPA electromagnetic slag detection ESD 100 with single sensor cassette

A general system layout of the actual system is shown in Fig. 0. The sensor in the ladle is connected by a plug in connector and signal transmission is carried out by preamplifier, slip rings and standard data cables to the central control unit where the slag alarm and control signals are generated.
The start up of a system including training is generally done within 5 working days. During the start up main attention is paid to the training of the people on site and the optimization between yield and quality depending on the casted steel quality. By communication via common fieldbus the slag limit can be set for each heat separately taking in consideration the casted steel quality.
Additionally to former systems new ones are equipped with a PC-based data recorder, allowing documentation and data analysis for quality insurance.

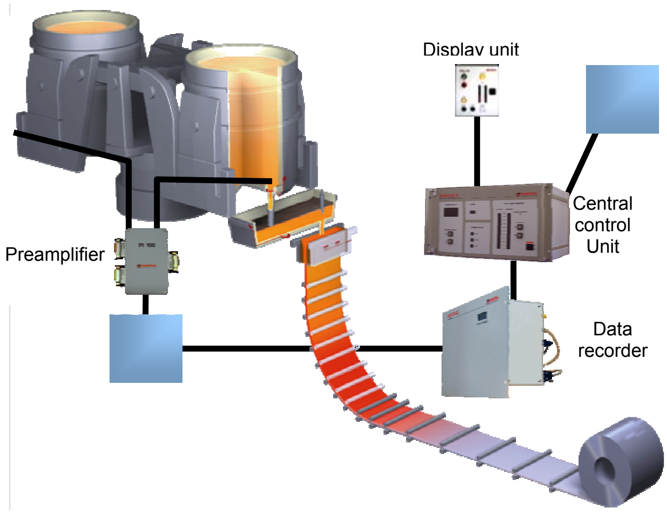

Fig. 0: System layout for electromagnetic slag detection

Supervising and analysing tools

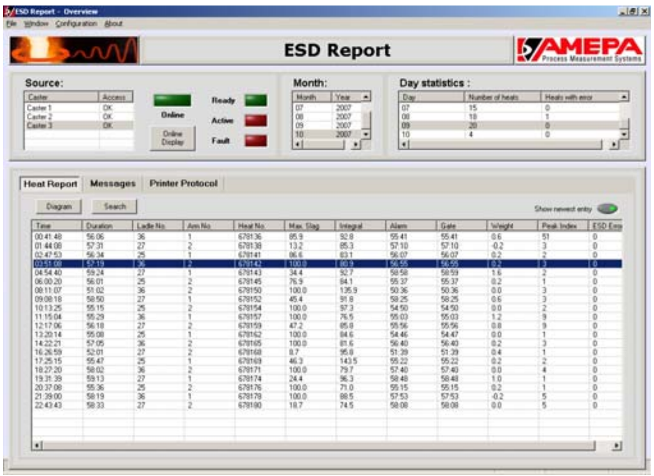

Fig. 0: Monthly and daily statistic display reporting display

The new possibilities of data recording by PC are nearly unlimited. Now with this technique it is possible to store information for one year or more.
All internal information combined with the process information like ladle number, heat number steel quality etc. are stored frequently. For each heat all analogue signals are sampled with a rate of 50 msec and stored on a hard disk, too.
The ESD Report software serves to visualize monthly and daily statistics and single cast measurements records.

The software can be installed on one or more customer computers allowing convenient acces to the monthly and daily statistics (Fig. 5) and measurement datas (Fig. 6) via an Ehternet connection, e.g. from an office work station.
Completed measurements can be analysed in “offline mode” or the user may view the data from ongoing measurements in “online mode”. This enables customers to easily supervise the ESD 100 system and to keep the system running 24 h the day.

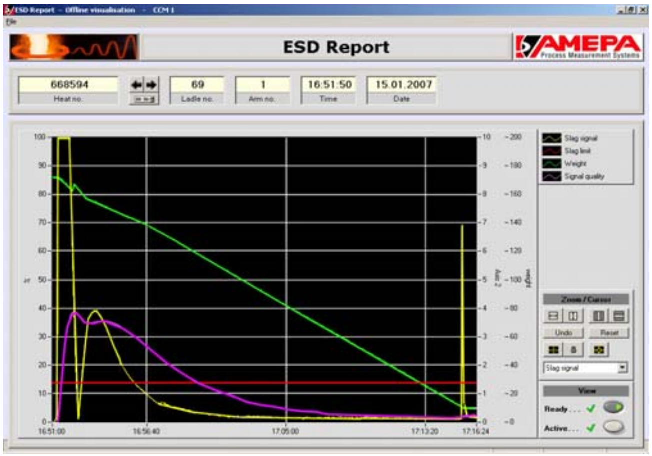

Fig. 0: Analogue signal display

Operational Results in last 20 years

Up to now a lot of publications report about the results achieved by using the ESD 100.

In Dauby et al.[4] it was reported a yield improvement of about 0,4 % - 1,02 % (Fig. 0) while the first 37 days after start-up whereby 12 ladles were equipped with slag detection sensors.

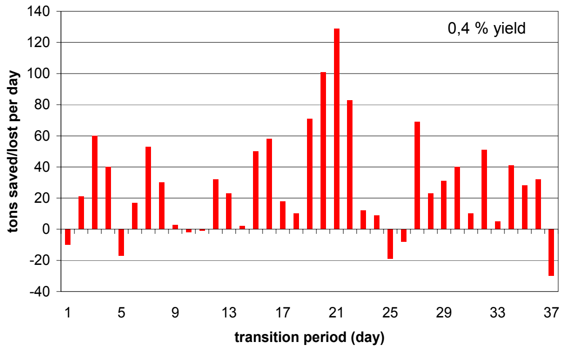

Fig. 0: Daily yield performance within the first 37 days after start up

An European steel plant reported that the slag carry over was reduced by more than 50 % from 69 kg to 31 kg by using an inner nozzle diameter of 80 mm. The results were verified by using tracer material in the ladle slag and measuring the quantity which reaches the tundish. At the same time an increase of the average tundish sequence length up to 50 % could be achieved without influencing inclusions conditions in the produced slabs.[5]
A South Korean steel plant reported amongst others a reduction of nozzle clogging from 32 times/month to 5 times/month only by the installation of the slag detection system.[6]
A big integrated Brazilian steel plant reported a reduction of slag carry over of about 87 % and therefore a reduction in the clogging index from 100% to 70%.[7]

Ultra slag detection

The requirements regarding product specifications and cleanness continually increased in the last years and there were discussions from time to time about further lowering slag carry-over for special steel grades. In spite of the high sensitivity of the current electromagnetic slag detector, the measurement principle requires a certain slag portion entrained into the steel flow to become detected. In most ladle drainage processes the steel slag transition takes about 3 –main vortex starts- to - 10 seconds to be completed.
In 1995 a study was published by Sankaranarayanan and Guthrie about drainage experiments with an oil layer on water.[8] Discrete oil droplets were entrained some time before the main vortex developed which itself occurred late during the emptying process.

If in steel-making ladles such discrete portions of slag regularly flowed before the main vortex flow starts and if it was possible to detect them, a much more sensitive slag detector could be developed. Moreover, the smallest slag portion to be carried over could be minimized to practically “zero slag”.

Detection of small discrete portions of slag entrainment

While the standard slag detector was developed to deal with increasing proportion of steel/slag transition in a time range between 3 and 30 seconds, an intelligent signal treatment has to distinguish between starting of main vortex as above mentioned or single droplets which only generates small impulses in the millisecond range (Fig. 0).

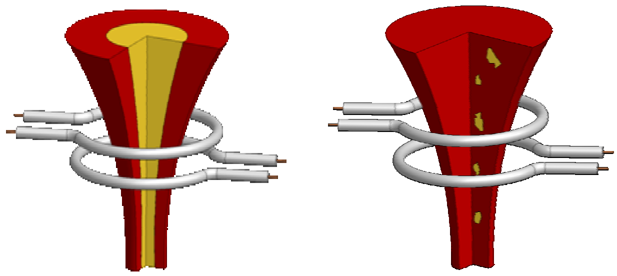

Fig. 0: Main vortex Droplets entrainment

The improved electromagnetic slag detector

To detect these small impulse signals, the current slag detector electronic ESD 100 was equipped with a second hardware channel and an additional signal processor board. The signal processing in the second channel was optimised for discrete slag portion detection. The second channel delivers a so-called “Slag Particle Signal” which indexes the volume of the discrete slag portion.
The first channel remained unchanged and delivers the known slag signal as in the former slag detector.

Plant measurement results with the improved slag detector

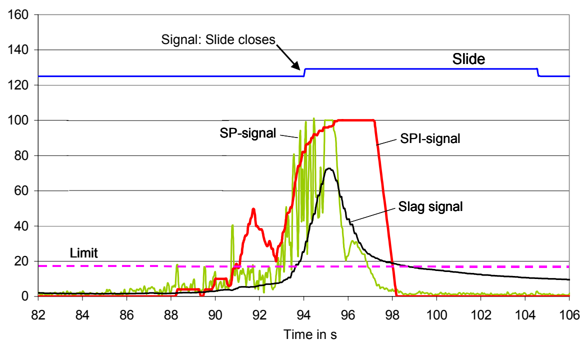

Fig. 0: Typical signal profiles of the new slag detection system

Fig. 0 shows a typical signal profile - as published by ThyssenKrupp Steel[9] - generated by the conventional slag detection system (slag signal) and the new system (SP signal).
The individual signal peaks of the SP signal are abstracted by means of an algorithm and converted into a new signal, the “slag-particle-Index” (SPI signal), that is monitored for the exceeding of a settable limit value.
If the limit value is exceeded, a preliminary alarm is triggered, allowing the casting ladle to be closed via the slide gate.
It can be seen that the SP signal of the new system in Fig. 0 has reacted earlier to the starting slag drops intreatment than the system conventionally in use. Clear signal fluctuations of the SP signal can be seen after just 88 s following activation of the system during final casting of the ladle, while the slag signal of the standard system only records negligible values before the main vortex flow starts. The SPI signal exceeds the limiting value which triggers a slag preliminary alarm approximately 2.8 s earlier than by the standard system.

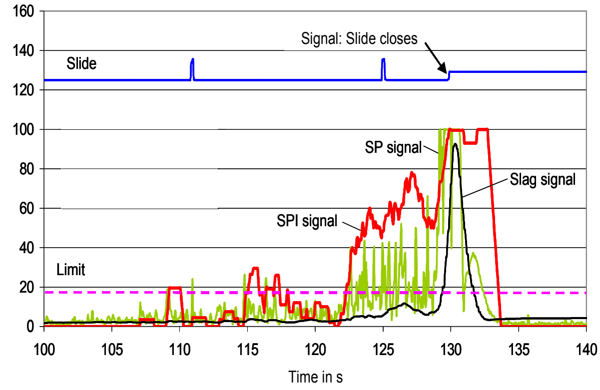

Fig. 0: Strong and long time slag carry-over by withdrawn slag clusters

Tests at a German steel plant using the new slag detection system showed that the transition between steel and slag flowing from the ladle does not take place into the tundish suddenly, but that there is a transition time in which initial traces of slag drops are already entrained in the steel flowing out of the ladle.

The duration of this transition time can vary very significantly. Fig. 0 shows the signal profile of the conventional system as well as of the upgraded system during a prolonged slag carry-over time.

It can be seen that the SP signal displays considerable fluctuations just 107 s after system activation that are obviously caused by individual slag clusters drawn from the slag layer in the casting ladle. The slag signal of the conventional detection exceeds the alarm limiting value 128 s after system activation. This means that the standard system allows certain slag quantities to enter into the tundish unnoticed.

Such slag quantities which are dropped in before the standard alarm is given are as a rule not deleterious for steels, even those of a higher quality grade; however, top quality steels intended for heavy-duty applications, as for tin plate or tyre cord, require that every possible inclusion of non-metallic impurities in the steel be avoided.

Comparison of detection characteristics of old and improved systems

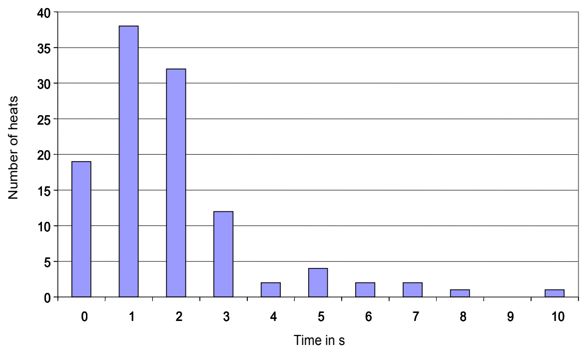

Fig. 0: Time delay conventional-new alarm

In order to compare the detection characteristics of both systems, the new slag detection system was run parallel to the standard system and the alarm time points of the systems compared.

Fig. 0 shows an incidence distribution of the time delay points in slag detection between the new and the conventional system for the heats under investigation.[7] It has been shown that the test system detects slag on average roughly between 1 and 2 s earlier leading to alarm generation than is the case with the standard system. In a not inconsiderable amount of the heat, however, a slag carry-over was detected by the new system significantly earlier.

Fig. 0 shows the effect of the new system on the average quantity of slag carry-over during ladle transfer. The standard system reduced already the carry-over quantities drastically; with the new slag detection further substantial reductions on for the top steel qualities could be achieved.

Slag carry-over minimisation versus yield-improvement requirements

The signal of the new (slag particle) channel allows interruption of the outflowing steel stream before the main slag flow starts.
If requested it can even be used to terminate draining as early as single portions of slag become entrained in the stream. Therefore the cleanness requirement for the most sensitive steel grades can be met in future by using the new instrument.
On the other hand, closing the slide-gate early means an increase in residual steel in the ladle. Most steel grades do not require being cast completely slag free. To be effective, cleanness requirements and yield have to be optimised for each steel grade.
While maximum yield can be achieved by using the current main slag channel (no.1) to alarm and close the slide-gate for high cleanness requirements the SPI-alarm channel (no.2) will be used.

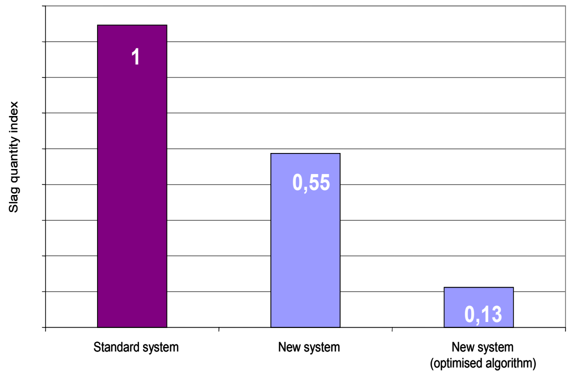

Fig. 0: Slag quantity index

Summary and Outlook

With its direct measuring principle and high signal-noise ratio, the electromagnetic slag detection ESD has reached the requested reliabilities and sensitivities needed for today's clean steel production and there is still enough potential to go further in future.
The main disadvantage of electromagnetic sensors was in former times the sensor life time – but over the last decades, the improvements in refractories and sensor protection helped to reach life times of years, so long that the sensor is not a concern any more. That in combination with the outstanding benefits gained with such a technology explains that the ESD has become and will be also in future the standard in clean steel production.

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